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Learning to teach climate change: students in teacher training and their progression in pedagogical content knowledge

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ABSTRACT

Climate change adaptation is a notorious example of a wicked problem. Teachers need to have extensive knowledge to design high-quality education that addresses the wickedness and contributes to wicked problem-solving. The components of the knowledge basis for teaching climate change issues can be highlighted with the Pedagogical Content Knowledge (PCK) framework. In the international, interdisciplinary course EduChange, pre-service teachers built their content knowledge and pedagogical content knowledge. They took part in a training week, where they explored issues related to climate change in different regions, acquainted themselves with place-based education and fieldwork, and were trained in educational design. Subsequently, they developed lessons for secondary schools. This paper describes the structure of the course, and explores how it contributed to the development of the PCK of the pre-service teachers. Survey data and interviews show that the participants valued the course. Although the pre-service teachers said the course contributed considerably to the development of their PCK, the lessons developed varied in respect to the wicked characteristics that were addressed and their potential for stimulating progression in wicked problem-solving.

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Wicked problems; climate change education; pedagogical content knowledge; place-based education; international course

Introduction

The need for climate change education

Mitigating climate change is urgent and giant leaps forward are necessary to avoid catastrophic climate change. Staying within a 2°C rise in global warming demands radical changes to the way we produce and consume energy, food and other products, the way we travel or build our homes. Besides mitigation, adaptation is also needed to reduce the impact of climate change (IPCC, 2014).

According to Termeer et al. (2013), adaptation to climate change can be seen as a "wicked problem par excellence". After reviewing the literature about wicked problems (e.g. Brown et al., 2010; Cantor et al., 2015; Jordan et al., 2014; Levin et al., 2007; Rittel &

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Webber, 1973; Termeer et al., 2013), we selected 11 wicked characteristics that, should be addressed in secondary education about climate change mitigation and adaptation:

(1) Climate change mitigation and adaptation is a complex issue with natural, technical, economical, societal, political and psychological dimensions, and is therefore hard to define.
(2) Climate change issues are connected to other issues, such as the need for housing, food production, etc.
(3) Climate change mitigation and adaptation requires infrastructural adjustments, such as conducting flood protection measures, as well as societal changes, such as increasing resilience among citizens.
(4) Global warming affects regions in different ways, for example, resulting in an increase in precipitation in one place and decrease in another place. Similarly, the vulnerability and adaptive capacity vary from place to place (IPCC, 2014). The effectiveness of measures also depends on the local conditions: there is no one-size-fits-all solution. In short: the local context matters.
(5) Climate change is an inequality issue. Both the causes and effects are unequally distributed among income groups, and therefore also spatially. Besides this, poor people and countries are more vulnerable to CC, and have a lower capacity to adapt to climate change (Roberts, 2010). Furthermore, there is also intergenerational inequality. Younger generations will be affected much more by climate change than older generations.
(6) There is a considerable amount of uncertainty in the risks (chances, times, effects), vulnerabilities and effects of measures. As a result, adaptation measures may lead to unforeseen consequences, creating a chain of change.
(7) Mitigating and adapting to climate change is highly resistant to solutions. New problems and solutions can emerge along the way.
(8) Climate change issues have many stakeholders, who often have conflicting interests.
(9) People can have different beliefs about the causes and risks of climate change, and the effectiveness of measures. They can also have different feelings about the earnestness (how serious the problem is), the distribution of responsibilities among stakeholders, and their capacities to take effective measures. This influences the willingness to act and support measures (see, for example, Eurobarometer, 2019). The fact that climate change is an inequality issue adds a moral dimension to people's opinions.
(10) People's world view and several psychological mechanisms influence how people judge information about the causes, risks and measures of climate change. As a result, information about the need for adaptation, and possible strategies for adaptation, is often contested.
(11) Due to the wicked characteristics outlined above, there are many controversies about what should be done.

Similar to the difference between knowledge-oriented "teaching about sustainability" and change-oriented "teaching for sustainable development" (De Wolf et al., 2018), we can distinguish between "teaching about wickedness" and "teaching for wicked problem-

solving". Karl et al. (2011) argue that the basis for tackling climate change is through collaborative, flexible and integrated decision-making processes at multiple scales that range from the local to the international. These processes require knowledge and skills among citizens and policymakers, as well as political and social will. To make change happen, awareness, a sense of urgency and of agency is needed. Climate change education can contribute to the development of the necessary knowledge, skills and attitudes so that students can become agents of change, as future consumers, policymakers, and social influencers (see, for example, Feja et al., 2019; Hoffman, 2019; Israel, 2012; Kuthe et al., 2019). Addressing young people as future citizens and policymakers, demands that education gives them insight into the wicked problem of climate change, and develops the competencies to contribute to solving climate change.

Although a clear theoretical framework of which competencies constitute wicked problem-solving is not yet available, the literature provides some useful building blocks. For example, Cantor et al. (2015) argue that wicked problem-solving requires the ability to handle complexity, and to deal with unpredictability. This could be achieved by developing students' system thinking skills (Arnold & Wade, 2015). As climate change issues contain many dimensions and are connected to other issues, it requires inter-disciplinary thinking skills to solve them (Baerwald, 2010; Weber & Khademian, 2008). This implies following an integrative, cross school subject approach (Brown et al., 2010; Weber & Khademian, 2008).

As the local context matters, students should develop observation skills and curiosity (Arnold & Wade, 2015), and skills in applying theoretical knowledge to real-world local problems (Lopatto, 2003). Cantor et al. (2015) also argue that wicked problem-solving requires collaboration skills (Cantor et al., 2015). This could be stimulated by letting students work together, and to connect education with local stakeholders (Arnold & Wade, 2015; Kindon & Elwood, 2009; Savin-Baden & Wimpenny, 2007).

Pauw and Beneker (2015) emphasize the importance of letting students think about probable, possible and preferable futures. Scenario-thinking skills and imaginative thinking skills (Brown et al., 2010) are therefore also valuable competencies for wicked problem-solving. Monroe et al. (2019) argue that wicked-problem solving requires skills in reflecting on viewpoints of yourself and other people. Finally, Batty (2013) argues that wicked problem-solving requires resilience in the face of setbacks and obstacles.

From this short overview, one can deduce the high demands set for climate change education to effectively support the development of these competencies. To date, however, climate change education often focuses on the development of the knowledge component, especially knowledge on the causes and mechanisms of climate change, and gives little systematic attention to the skills and attitude components (e.g. Bosschaart, 2019). Furthermore, education is often rather "traditional": teachers are providers of knowledge and schoolbooks present fixed futures (Pauw & Beneker, 2015). As a result, young people perceive climate change as something abstract and distant (Bosschaart, 2019). Moreover, students do not learn how to handle unpredictability, and may not feel that they can be agents of change.

After a systematic review of literature on climate change education, Monroe et al. (2019) conclude that it is important to bring climate change close to students: to engage them and to make it personally relevant for them. Climate change education should therefore focus on the visible effects of climate change in the daily environment of

students, and focus on effects that can be noticed, such as water issues. Heavy rains can be observed and affect people directly. The same applies to flood protection measures.

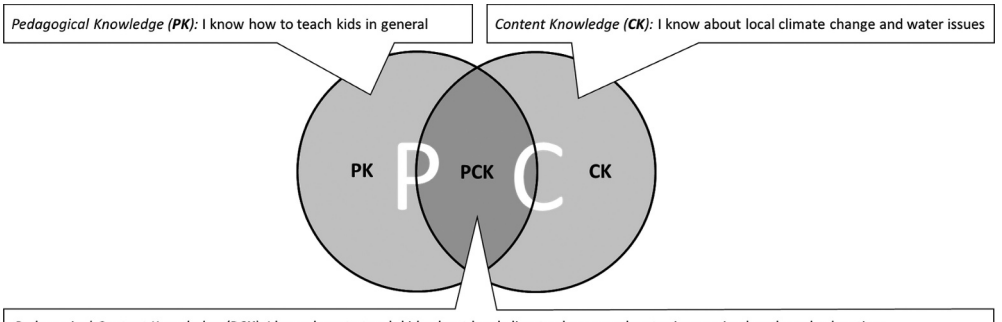
Fieldwork and place-based education can give students insight into the wickedness of climate change adaptation issues, and develop competencies in wicked problem-solving. Fieldwork encompasses "any component of the curriculum that involves leaving the classroom and learning through first-hand experience" (Boyle et al., 2007, p. 300). Many authors in this journal have stated how fieldwork is essential to teaching geography. It is often emphasized that fieldwork can facilitate learning, for example, by connecting theory with the real geographical world outside, and by connecting cognitive with affective processes (Dummer et al., 2008; Dunphy & Spellman, 2009; France & Haigh, 2018; Hope, 2009; Kent et al., 1997; Nundy, 2001; Peacock et al., 2018; Scott et al., 2006; Wilson et al., 2017). When well planned and executed, fieldwork can lead to deep learning (Dummer et al., 2008; Oost et al., 2013; Reilly et al., 2016).

Fieldwork confronts students with the real world and trains them to observe (competency 1) and to apply theoretical knowledge to real-world situations and problems (competency 4). Fieldwork that moves beyond classic, teacher-led "look-see" tours to more student-centred approaches allow students to practice social skills (competencies 5 and 6) as well and can contribute to personal development (competency 9).

Place-based education recognizes the importance of local knowledge and lived experiences for learning, forging connections with the local community and aiming to create critical active citizens (Gruenewald, 2003, 2008; Israel, 2012; Smith, 2002; Sobel, 2005). According to Davis and Thompson, J. (2013), place-based climate change education can lead to deeper understanding of the issues as place-based education can "use place as a medium; and connect that place to emotional and social meanings through messages about localized impacts of climate change" (Davis, 2014, p. 65). Moreover, place-based education aims to connect students with local environments and instil in them a sense of agency and engage them to take part in local action to solve environmental and social issues (Khadka et al., 2020; McInerney et al., 2011). As such, place-based approaches can help overcome the many challenges climate change educators face (Littrell et al., 2020). Inherent in place-based education is therefore the connection to local stakeholders and the confrontation with several perspectives and knowledges (competencies 5 and 6).

The competencies needed to design and conduct climate change education

This brief overview demonstrates the high demands put on teachers. They need to develop an extensive knowledge base to be able to design and carry out effective climate change adaptation education. According to Shulman's (1986) Pedagogical Content Knowledge (PCK) framework, (future) teachers need to have knowledge in the fields of Pedagogy (P) and Content (C), and knowledge at the intersection of these fields. First, they need generic *Pedagogical Knowledge (PK)*, which includes knowledge about how to design and conduct lessons in general. In addition, they need to understand the impacts of climate change and how this varies from place to place, and have knowledge about adaptation measures. This can be seen as *Content Knowledge (CK)*, also called *Subject Matter Knowledge (SMK)*. PK and CK alone do not define a good teacher. Teachers also need to develop a specific kind of knowledge at the interplay of Pedagogy and Content, which Shulman named *Pedagogical Content Knowledge (PCK)*. The PCK framework has



*Pedagogical Content Knowledge (**PCK**):* I know how to teach kids about local climate change and water issues via place-based education

Component	*Explanation*
1: "Orientation"	Awareness of one's own beliefs about the purposes of teaching about local climate change and water issues
2: "Curriculum"	Knowledge about the position of climate change and water issues in the curriculum
3: "Student understanding"	Knowledge about preconceptions and attitudes of students regarding local climate change and water issues
4: "Instructional strategies"	Knowledge about how to transform knowledge about local climate change and water issues so that it becomes accessible for students, how to design place-based education tasks, and how students learn when they work on these tasks
5: "Assessment"	Knowledge about how to assess students' progression in knowledge about local climate change and water issues

Figure 1. Shulman's (1986) PCK framework, specified for teaching about climate change and water issues via place-based education.

subsequently been refined by several authors (Fernandez, 2014). Magnusson et al. (1999) identified five components of PCK: "orientation"; "curriculum"; "student understanding"; "instruction strategies"; and "assessment". In Figure 1, we specified the PCK framework for teaching about climate change and water issues via placed-based education.

Aim of this paper

The PCK of pre-service teachers in geography and environmental education has been studied by several authors (e.g. Blankman et al., 2015; Clausen, 2017; Injeong & Bednarz, 2014), but not yet in relationship to teaching wicked problems such as climate change. This paper describes the design of a course called *EduChange*, which focused on teaching climate change adaptation issues, and explores the development of the PCK of the pre-service teachers during the course. It does so by systematically explaining the design of the course in relation to the pre-service teachers' PCK and the wicked characteristic that climate change education should tackle.

Characteristics of the EduChange course

Overall design

The EduChange course was set up by ten lecturers and teacher trainers from universities in Olomouc (Czech Republic), Malta, Trondheim (Norway) and Utrecht (Netherlands) in the form of an Erasmus+ partnership. It was designed for students in geography, science and environmental education at the four universities, in order to equip future teachers with knowledge, skills and attitudes to teach climate change and water issues at

secondary schools, and to innovate pre-service teacher education. Each year, there was place for six to eight students from each university – ensuring a mixed group: international and interdisciplinary.

The pre-service teachers participated in a training week in February (Table 1), during which they met in Olomouc (cohort 1, 2018), Malta (cohort 2, 2019) or Utrecht (cohort 3, 2020). The program consisted of lectures, workshops, fieldwork and social activities. In March and April, the pre-service teachers designed lessons in pairs or triads, and implemented them in local secondary schools. The whole group of pre-service teachers met again in May in Trondheim (cohorts 1 and 2) or online (cohort 3) to share their experiences and reflect on their lessons, and to expand their knowledge by following follow-up workshops and fieldwork. In between the three cohorts, the program of the course was adapted on the basis of evaluations among participants and experiences of the EduChange team. Table 2 summarizes the activities of the final design of the EduChange course in 2020. The following sections highlight some important characteristics of the design. Subsequent sections explore how the EduChange course contributed to the PCK of the participants.

Internationalization

Research on the development of PCK of science teachers showed that a coherent basis of CK is a prerequisite (Sanders et al., 1993). The development of this CK about spatial variability in climate change and water issues (the fourth characteristic of wickedness) was stimulated via activities, such as a research poster assignment, lectures and fieldwork. In the latter two, attention was paid to the wickedness of the problem, although the 11 wicked characteristics were not addressed explicitly.

An important assumption of the EduChange course was that internationalization would allow pre-service teachers to experience how climate change and water issues vary between the four countries and that this would add to their understanding of the whole issue (see the fourth characteristic of wickedness). The differences between the four countries are profound, regarding the type of climate change threats, the vulnerability and adaptive capacity. As the inhabitants of these countries face different issues, they have different perspectives on climate change (the ninth characteristic of wickedness). In the EduChange course, internationalization was therefore not just about seeing and hearing about other places, but also about meeting and discussing climate change with fellow students from different places.

Table 1. Design of the EduChange course.

Cohort	February	March	April	May	June
1 (2018)	Training week in Olomouc	Designing lessons in home countries	Testing lessons in home countries	Reflection week in Trondheim	Wrap up
2 (2019)	Training week in Malta	Designing lessons in home countries	Testing lessons in home countries	Reflection week in Trondheim	Wrap up
3 (2020)	Training week in Utrecht	Designing lessons in home countries	Testing lessons in home countries	Online reflection week (due to Covid-19)	Wrap up

Table 2. Activities of the design for the training week (T0–T6) and online reflection week (R1–R5) of the EduChange course in 2020; the knowledge and skills that were explicitly (E) or implicitly (I) addressed in these activities; the connection with EduChange concepts; and the summarized survey data on a 1–10 scale ($N = 28$) (see the "Results" section).

		Components of the teacher knowledge *basis*						EduChange concepts			Survey data	
Day	*Activity*	*CK*	*PCK "orientation"*	*PCK "Curriculum"*	*PCK "Student understanding"*	*PCK "Instruction strategies"*	*PCK "Assessment"*	*Interdisciplinarity*	*Internationalization*	*PBE & fieldwork*	*X*	*std*
T0	Ice-breaking event	-	-	-	-	-	-	-	E	-	-	-
T1	Introduction (welcome, goals and logistics)	-	-	-	-	-	-	-	-	-	-	-
	Workshop "Fieldwork"	-	I	-	-	E	-	-	-	E	7.7	1.4
	Presentation "Water system of the Netherlands"	E	-	-	-	-	-	I	-	-	9.0	1.1
	City tour "History and water system of Utrecht"	E	-	-	-	-	-	-	-	E	-	-
	Workshop "Environmental game"	-	I	-	-	I	-	-	I	-	8.2	1.3
T2	Presentation "Youth perspectives on CC"	-	-	-	E	-	-	-	I	-	8.9	1.0
	International lunch	-	-	-	-	-	-	-	E	-	-	-
	Poster presentations and discussion	E	-	-	-	-	-	E	E	-	7.8	1.3
T3	Workshop "Educational Design"	-	I	-	-	E	-	-	I	-	7.6	1.5
	Fieldwork at the river Rhine	E	-	-	-	I	-	I	I	E	8.9	1.1
T4	Workshops "Photostories", "Place-based education", "Survey apps" and "Virtual Reality"	-	I	-	-	E	-	-	-	E	8.4	1.2
	Brainstorming and developing lessons	-	-	-	-	I	-	I	I	I	7.9	1.4

(*Continued*)

Table 2. (Continued).

		Components of the teacher knowledge *basis*						EduChange concepts			Survey data	
Day	*Activity*	*CK*	*PCK "orientation"*	*PCK "Curriculum"*	*PCK "Student understanding"*	*PCK "Instruction strategies"*	*PCK "Assessment"*	*Interdisciplinarity*	*Internationalization*	*PBE & fieldwork*	*X*	*std*
T5	Fieldwork in the peatlands district near Gouda	E	-	-	-	I	-	I	I	E	9.3	0.8
T6	Brainstorming and developing lessons	-	-	-	-	I	-	I	I	I	7.9	1.4
	Prototype lesson presentations and discussion	-	-	-	-	I	-	I	I	I	8.3	1.1
	Reflection and evaluation	I	I	I	I	I	I	I	I	I	-	-
	Farewell dinner	-	-	-	-	-	-	-	E	-	-	-
R1	Introduction (welcome, goals and logistics)	-	-	-	-	-	-	-	-	-	-	-
	Presentation of lessons and experiences (part 1)	-	-	-	-	I	-	I	I	I	7.2	1.4
	Presentation "education for sustainable development"	-	I	-	-	E	-	-	-	-	7.8	1.3
	Virtual fieldwork Tautra	E	-	-	-	I	-	I	-	E	6.6	1.7
	Online pub-quiz	-	-	-	-	-	-	-	E	-	-	-
R2	Presentation of lessons and experiences (part 2)	-	-	-	-	I	-	I	I	I	7.4	1.4
	Virtual fieldwork Trondheim	E	-	-	-	I	-	I	-	E	7.8	1.1
R3	Workshop "Assessment of CC education"	-	-	-	-	-	E	-	-	-	8.3	1.1
	Expert feedback on lesson	-	-	-	-	I	-	-	-	I	7.7	1.2
	Adapting the lesson	-	-	-	-	I	-	-	-	I	-	-

(*Continued*)

Table 2. (Continued).

		Components of the teacher knowledge *basis*						EduChange concepts			Survey data	
Day	*Activity*	*CK*	*PCK "orientation"*	*PCK "Curriculum"*	*PCK "Student understanding"*	*PCK "Instruction strategies"*	*PCK "Assessment"*	*Interdisciplinarity*	*Internationalization*	*PBE & fieldwork*	*X*	*std*
R4	Presentation "geospatial technologies and CC"	E	-	-	-	-	-	-	-	-	8.3	1.1
	Virtual fieldwork Trondheim mountains	E	-	-	-	I	-	I	-	E	7.5	1.1
	Presentation "Curriculum for the Anthropocene"	E	I	-	-	-	-	E	-	-	8.0	1.6
R5	Reflection and evaluation	-	-	-	-	-	-	-	-	-	-	-

Interdisciplinarity

Due to the complexity of the issue (the first characteristic of wickedness), teaching climate change requires an interdisciplinary approach. We therefore recruited pre-service teachers with different backgrounds, in particular from geography education, environmental education, science education, environmental sciences and geospatial technologies. The future teachers shared an interest in climate change and sustainability, a perceived urgency to act upon climate change and a desire to reach young people with these messages. Each participant brought in their own expertise, their CK thus varied. All participants were acquainted with fieldwork methodologies specific to their disciplines – this is also part of CK. Finally, about a quarter of them had previous experience with secondary education, and therefore possessed some PK and PCK. During the training week, we let participants from different backgrounds work together in teams, so they could share and combine their knowledge.

As the process of conducting research provides opportunity for learning (Brew, 2012), we gave the pre-service teachers in cohorts 2 (2019) and 3 (2020) a small literature research project studying a regional climate change or water issue. The assignment included literature review, an abstract, peer review, and a poster presentation. Posters can form a creative alternative to papers. When developing posters, "students crystallize their own arguments" (Lynch, 2017, p. 638). In the second cohort, students were free to choose a topic and region. To make the task more relevant, students in the third cohort were instructed to focus on an issue in their own country. The pre-service teachers chose topics such as the risks of climate change induced landslides in the Trondheim area, sand supplementation on the Dutch coast, flash floods in the Czech Republic, and salinification of groundwater in Malta. During the training week, participants presented their posters in a symposium and discussed the differences in the effects of climate change and in adaptation policies between countries.

Fieldwork and place-based education

As seen in the "Introduction" section, fieldwork and place-based education can be instrumental in providing students with insight into various characteristics of wickedness of climate change adaptation, and develop several wicked problem-solving competencies. Therefore, between a third and a half of teaching hours of the training and reflection week were spent out in the field, with the aim to increase the future teachers' knowledge about climate change and water issues as well as their knowledge about fieldwork methodologies (which are both CK). The fieldwork was always connected to the broader issue of how climate change affected water issues, and how to adapt to the effects. During fieldwork, visiting pre-service teachers could learn from experiencing new places, while the pre-service teachers of the host institute could see their country through the eyes of strangers.

Fieldwork varied from teacher-led "look and see" excursions to inquiry-based fieldwork (cf. Oost et al., 2013). Although student's experiences of fieldwork partly depend on what can be seen at the site and practical issues such as weather conditions, it seemed that the participants valued the student-centered fieldwork higher than the teacher-led excursions. During such excursions, we noticed that half of the group was not actively paying attention. Small research tasks, on the other hand, activated them. In order to

keep students involved and to contribute to deep learning, we decided to include many research tasks in the fieldwork in third cohort 3 (2020).

After the fieldwork, we discussed the characteristics of the fieldwork design with the students, and explained how we tried to make the fieldwork relevant, consistent, practicable and effective. Furthermore, a part of the group participated in a half-day workshop on place-based education. In such a way, we hoped that they would develop knowledge in the "instructional strategies" component of PCK.

Connection to preconceptions

Climate change education can only be effective when it tunes in to its audience (Kuthe et al., 2019). In the training week, we therefore included a presentation about how young people think about climate change, based on international research. This concurs with Van Driel et al. (1998) recommendation to let pre-service teachers study preconceptions of secondary students. The presentation focused on psychological mechanisms related to climate change perceptions such as distancing, delay discounting, and the discrepancy between opinions about the severity of the problem and willingness to act (see, for example, Bosschaart, 2019). This connects to the ninth characteristic of wickedness. Furthermore, we discussed how to overcome this problem, and stimulate young people to feel the urgency and become agents of change. This aimed to build knowledge in the "student understanding" and "instruction strategies" components of PCK.

Learning from designing, conducting, reflecting and sharing

An important part of the EduChange philosophy was that the participants would put the knowledge and skills they gained during the training week into practice. We therefore let them work in small teams and design lessons about climate change and water issues for their local school. The transformation of roles – from taking part as students to becoming teachers requires a transformation of CK and operationalisation of PCK.

An important observation we made as lecturers after the first cohort 1 (2018) was that many pre-service teachers needed more guidance and support in educational design. A couple of them already had some experience, but most did not. We observed how some of them struggled with formulating clear learning objectives and thus stuck to the official curriculum as their guideline, others were focused on practicalities or put more emphasise on the format than on the objectives or content. We therefore included a half-day workshop in the training week of subsequent cohorts, which mainly focused on formulating learning goals, transforming content into content for use in educational setting, and designing challenging tasks. This connected to the "instruction strategies" component of PCK.

Several authors (e.g. Magnusson et al., 1999; Sobel, 2005) argue that PCK especially develops with (reflection on) experience. We therefore let the pre-service teachers conduct their lessons. As reflection (Park & Oliver, 2008) and sharing experiences (Dogan et al., 2016) can significantly contribute to the development of PCK, the pre-service teachers also had to evaluate their lessons, and present their findings during the reflection week in May. Afterwards, participants revised the materials. The revised materials are available via http://educhange.net.

Reflection was stimulated in the reflection week with the help of two interactive lectures, one on methods of education for sustainability and another one on how to assess progression in students' thinking. Both lectures stimulated the pre-service teachers to think not only about cognitive but also about affective and conative learning objectives, and therefore connected to the "orientation" and "assessment" components of PCK.

The reflection week of the second and third cohorts (respectively 2019 and 2020) also included a presentation about the "Curriculum of the Anthropocene", which challenged the pre-service teachers to reflect on what they would like to achieve in education about climate change and why. Doing so, we tried to make future teachers more aware of their own beliefs about the purposes of teaching climate change, which falls under the "orientation" component of PCK.

Methods

The EduChange course thus aimed to contribute to pre-service teachers' CK and PCK in several ways. In order to gain insight into how the participants developed their knowledge basis and to evaluate and improve the program, several types of data were gathered. This paper analyses the data gathered in the third and final cohort (2020), to evaluate the learning of the pre-service teachers who participated in the EduChange course.

First, the posters created by the pre-service teachers were analysed. For each poster, it was analysed which of the 11 characteristics of wickedness outlined in the introduction section were addressed, and to what degree students were able to solve the wicked problem. As the posters were made before the start of the training week, they can be seen as a pre-test.

Second, observations were made by the EduChange team during the activities focusing on what students said and did, in relationship to the tasks. Observations about students learning behavior were supplemented by informal conversations with students during the program and semi-structured reflection sessions at the end of the training week and reflection week. The observations and utterances of reflection were registered in logbooks and discussed with the other team members.

Third, online surveys were conducted at the end of the training week and reflection week. Students were asked to rate the different activities (field work, workshops etc.). They also had to rate in which degree the characteristics of the program (internationality, interdisciplinary, fieldwork) had contributed to their learning, and asked to explain their answer.

Additional survey questions were included in the survey conducted at the end of the reflection week, in which the participants were asked to rate the contribution of the course to the development of their knowledge and skills in the different components of PCK on a 1–5 Likert scale, followed by open questions in which students were asked to explain what contributed most to the development of their knowledge and skills. The results of the additional survey questions were discussed in online focus group interviews with all participants, in which the pre-service teachers were asked to further explain their answers.

Fourth, the lessons created by Dutch and Norwegian students were analysed by searching for characteristics of wickedness that are addressed, and wicked-problem

solving competencies that are stimulated. As the lessons were the end products made by the participants, they can be seen as a sort of post-test. The lessons of the other students were not analysed, as the authors of this paper do not speak Czech or Maltese.

Results

Analysis of the posters

Although all research posters dealt with highly wicked local or regional climate change issues, the student pairs and triads addressed only between three and six characteristics of wickedness in their posters (*Table 3*). The complexity of the issue and connection with other issues was addressed in every poster. The most frequently mentioned other problems were the increased need for housing and pressures on the ecosystem. Six posters addressed the importance of the local context, making a comparison with other regions, or explaining how the measures were tuned to the specific characteristics of the water system in this region. Other characteristics of wickedness were only addressed in a limited number of posters, or not addressed at all.

The EduChange team tried to raise group discussions connected to the poster presentations to a higher level by asking questions related to characteristics of wickedness that were not addressed in the posters. It turned out that some students were aware of these characteristics of wickedness, but had not included it in their posters.

Perhaps higher learning outputs could have been achieved when students were given the task to explicitly reflect on the wicked characteristics of the issue beforehand, when they carried out their research and developed their posters. However, this may be less motivating than more open tasks. The question of what the right amount of structure is has not yet been solved.

Evaluation of the course (based on surveys, interviews and observations)

Fieldwork received the highest scores of all activities in the course in cohort 3 (Table 2). In the open questions, about half of the pre-service teachers said that the fieldwork was interesting, illustrative and fun and pointed at the pedagogical benefits of fieldwork in general: "It is one thing to read about it, and another thing to experience it." Of the particular method applied during the fieldwork at the River Rhine, one pre-service teacher noted that "the method motivated me to pay attention and try to understand what we were looking at."

At several instances, we observed that the confrontation in the field with the "otherness" (e.g. France & Haigh, 2018) contributed to their learning. Students were confronted with unfamiliar landscapes and different climate change issues from home. At times, participants had to overcome some disbelief. In cohort 2 (2019), the issue of expansion of forest to higher altitudes in the mountains around Trondheim initially led to surprised responses from the participants from other countries and even jokes of it being a non-issue. There was similarly laughter when Dutch participants saw projections of the impact of 7 m sea level rise for Trondheim ("You are worried about maybe 100 houses. But for The Netherlands, this would mean that 10 million people would have to move!"). In cohort 3 (2020), participants from Norway, Malta and Czech Republic found it strange to see new houses

Table 3. Characteristics of wickedness of climate change adaptation that were addressed in the posters of cohort 3 (2020).

Group	Poster title	1) Complex issue[a]	2) Connected with other issues[b]	3) Requires infrastructural as well as societal change	4) The local context matters	5) Inequality issue	6) Uncertainty	7) Resistant to solu-tions	8) Conflicting interests	9) Different beliefs and feelings	10) Contesting of Information	11) Controversies about what should be done	Total
Malta 1	Water management	x	x						x				3
Malta 2	No drops, no crops	x	x		x				x				4
Malta 3	Malts's freshwater crisis	x	x					x					3
Norway 1	Urban vegetation and climate change	x	x						x				3
Norway 2	Quick clay hazards in Trøndelag	x	x		x		x	x				x	6
Netherlands 1	Retention ability of landscapes	x	x		x		x					x	5
Netherlands 2	Climate adaption – Living below sea level	x	x	x					x				4
Czech Rep 1	Water management and CC adaption	x	x		x						x	x	5
Czech Rep 1	How does climate change effect flood risks?	x	x		x								3
Czech Rep 2	Weather change in Liberec region	x	x		x		x	x					5
Total		*10*	*10*	*1*	*6*	*0*	*3*	*3*	*4*	*0*	*1*	*3*	

[a]At least 2 dimensions were mentioned; [b]at least one other issue was mentioned.

being built at 7 m below sea level in the Western part of the Netherlands. However, the initial giggling was often followed by questions geared at clarification and gaining deeper understanding. Likewise, questions from the lecturer, such as "What if you had a job, family and friends in this town: would you buy a house here?", led to interesting discussions. It was at these moments that the wickedness of the issues at hand clearly surfaced: conflicting interests, and the absence of solutions that satisfy everyone. Some pre-service teachers said that experiencing these places in the international and interdisciplinary group made a difference for their learning. For example, a Czech student explained, "During the discussions, you can hear other opinions. See different perspectives. That made the fieldwork important".

Although the virtual fieldwork in the online reflection week was designed by teachers who had considerable experience with VR fieldwork, they scored lower than the real fieldwork (Table 2). Three students noted that the impact was less than that of a real fieldwork, or that the experience could not compete with actually seeing a place. It is more difficult to address the affective component in a virtual fieldwork, and more difficult to organize interaction in an online environment. Perhaps higher outcomes can be achieved when 360-degree photos from several years are used, so that participants could investigate how places change over time as a result of climate change or of adaptation measures. Unfortunately, such time series were not available.

The pre-services teachers said that the literature research and poster presentation task also contributed to development of understanding that the local context matters in climate change adaptation issues. In the focus group interviews, one pre-service teacher noted, "The symposium was a great way of getting insight into every country's individual water issues. I liked the distribution of time: a little bit for presentations, a lot of time for discussion".

Three interactive lectures also stood out in terms of enthusiastic response by the participants. One pre-service teacher explained, "I really enjoyed learning about attitudes and it gives an important perspective for the designing of our lessons later on". In their lessons, some explicitly connected with the perceptions and preconceptions that prevent people from taking climate change seriously. Both the lecture on assessment and methods for ESD made students aware of a need to go beyond cognitive learning objectives. After the lecture on assessment, one student felt that the lecture had given her "words and ideas" that matched with what she felt she wanted to achieve with climate change education.

Evaluation of knowledge development (based on surveys and interviews)

Table 4 shows how the participants valued the contribution of the EduChange course for their development of knowledge and skills in the different components of the PCK model. The table shows that the pre-service teachers especially valued the course as it showed them how climate change can have different effects in different places (X = 4.8). A Czech student explained the benefits for education: "It's good to have these insights. I feel more confident now in teaching, I have examples now." A Maltese student noted, "I think it is really important to show kids that we cannot look for the same solutions at every place, because it doesn't make any sense. The effects of climate change are so diverse. Different people need to change their lifestyle, but in different ways." Internationalization thus added to the development of their CK, and also provided

Table 4. Contribution of the course for the development of knowledge and skills.

				What contributed most to your learning? (frequencies)												
	How did EduChange contributed to the development of your . . .." (1-5 Likert scale)	***X***	***STDEV***	*climate change and water Lectures*	*fieldwork*	*virtual fieldwork*	*posters*	*educational lectures*	*workshops*	*discussions with peers*	*discussions with teachers*	*exploring GeoSpatial Technologies*	*designing lessons*	*discussing lessons with peers/ teachers*	*testing lessons in schools*	*I already possessed the knowledge/skills*
CK	knowledge about the mechanism and causes of climate change	3.3	1.1	11	19	1	9				2					
	knowledge about the effects of climate change in different places	4.8	0.4													
	knowledge about strategies for climate adaptation in different places	4.3	0.5													
	skills in geographical and environmental fieldwork methodologies	4.4	0.7													
	skills in geographical and environmental literature research	3.6	0.9													
PCK 'Orientation'	vision about what you want to achieve with climate change education. and why you want to achieve this	4.3	0.7		3		3	12	3		2				1	

(*Continued*)

Table 4. (Continued).

				What contributed most to your learning? (frequencies)												
	How did EduChange contributed to the development of your . . .." (1-5 Likert scale)	X	STDEV	climate change and water Lectures	fieldwork	virtual fieldwork	posters	educational lectures	workshops	discussions with peers	discussions with teachers	exploring GeoSpatial Technologies	designing lessons	discussing lessons with peers/ teachers	testing lessons in schools	I already possessed the knowledge/skills
PCK 'Curriculum'	knowledge about the position of climate change and water issues in the curriculum	3.0	1.0		1		1	3		4	1		5			3
PCK 'Student understanding'	knowledge about students' preconceptions and attitudes towards climate change and water issues	3.5	1.1		2			18		1	1					1
PCK 'Instruction strategies'	knowledge about how to transform content about climate change and water issues so that it can be used in education	4.2	0.7		4*			6	7	2	4		4	6	2	
	knowledge about how to design in-class tasks in which students investigate climate change and water issues	4.0	0.7													
	knowledge about how to design fieldwork and place-based education tasks about climate change and water issues	4.6	0.6													
	knowledge about how students learn when they work on such tasks	3.4	1.2													

(*Continued*)

Table 4. (Continued).

				What contributed most to your learning? (frequencies)												
	How did EduChange contributed to the development of your . . ..” (1-5 Likert scale)	*X*	*STDEV*	*climate change and water Lectures*	*fieldwork*	*virtual fieldwork*	*posters*	*educational lectures*	*workshops*	*discussions with peers*	*discussions with teachers*	*exploring GeoSpatial Technologies*	*designing lessons*	*discussing lessons with peers/ teachers*	*testing lessons in schools*	*I already possessed the knowledge/skills*
PCK ‘Assessment’	knowledge about how to assess students’ progression in knowledge about climate change and water issues	3.3	0.9					13	3		7		3			

ideas on how to use the geographic knowledge in educational settings, which is part of the "instruction strategies" component of PCK.

The pre-service teachers indicated that the project contributed to the development of their vision about what they want to achieve with climate change education and why they want to achieve that (X = 4.3), although the program did not contain any activities that explicitly focused on the "orientation" component of PCK. The educational lectures, especially the one about the Anthropocene, were mentioned 12 times as important activities for the development of their vision. One pre-service teacher explained, "The information [in the lecture about the Anthropocene] was not new to me, but now I realized that we shouldn't tell the children a simple black and white story. Climate change is a complex issue. And we should make sure that kids realize that."

The knowledge development in the "curriculum" component of PCK was limited, with an average score of 3.0. This is probably because the pre-service teachers were not explicitly stimulated to investigate the position of climate change in the National Standards. Still, 5 (out of 28) mentioned that they had done so when they designed lessons. Four other pre-service teachers said that they learned a lot from discussions in peer groups. This was further explained in the interviews: "From talk with other students I learned that our curricula have different ways of approaching nature"; "It [discussions with peers] did make me think about how the lessons in different countries are similar or very different."; and "I now see some more connections between climate change and other subjects. It [climate change] is a very intersubject topic connecting geography, biology, history, physic, chemistry and math."

Regarding the component "instruction strategies", the pre-service teachers felt that they learned to transform content about climate change and water issues so that it becomes available for use in educational settings, and to design in-class and fieldwork tasks (X = between 4.0 and 4.6). However, they gained less knowledge about how the tasks work out in practice (X = 3.4, Stdev = 1.2). The low score can be explained by the COVID-19 crisis, due to which most pre-service teachers had to test their lessons online, or cancel the tests. When asked what contributed most to their learning, they mentioned a wide range of activities. Designing and discussing lessons with peers and teachers was mentioned 10 times in total. One Czech student said, "Especially designing lesson plans, and getting feedback from peers and teachers was valuable". The workshops (7x) and educational lectures (6x) were also mentioned. A Norwegian student explained, "I learned about the need to connect to local context, and to address *psychological distancing*. I knew about distancing before from environmental psychology, but not how to deal with it". Furthermore, four participants mentioned the fieldwork in the EduChange program, as they provided good examples. The pre-service teachers valued the debriefings of the fieldwork: "The discussion about the methodology in next morning was a good addition to think about setting up fieldwork". In such a way, the fieldwork had a modelling function.

Regarding the fifth component of PCK, "assessment", most pre-service teachers said that the lecture about assessment contributed most to their learning. Moreover, seven participants mentioned that they had learned a lot from talks with teachers.

In the surveys conducted after the training and online reflection week, the item "Being in an international group was an added value for the learning experience" scored on average respectively a 4.6 and 4.4 on a 1–5 Likert scale. The focus group interviews

Table 5. Analysis of the final design of the lessons developed by Dutch and Norwegian pre-service teachers in cohort 3 (2020).

		Wicked characteristics that are addressed													*Wicked problem-solving competencies that are addressed*								
Group	*Lesson title*	*1) Complexissue*	*2) Connectionwithotherissues*	*3) Requiresinfrastructuralaswellassocietalchange*	*4) Localcontextmatters*	*5) Inequalityissue*	*6) Uncertainty*	*7) Resistancetosolutions*	*8) Multipleinterests*	*9) Differentbeliefsandfeelings*	*10) ContestingofInformation*	*11) Controversiesaboutwhatshouldbedone*	*Total*	*1) Observationskills*	*2) Imaginativethinkingskills*	*3) Interdisciplinarythinkingskills*	*4) Skillsinapplyingtheoreticalknowledge*	*5) Collaborationskills*	*6) Skillsinreflectingonviewpoints*	*7) Systemsthinkingskills*	*8) Scenariothinkingskills*	*9) Beingresilientinthefaceofsetbacks*	*Total*
Netherlands 1	Reducing flood risks in the Gelderse Vallei	x	x	x	x				x	x		x	*7*		*x*	*x*	*x*	*x*	*x*		*x*	-	*6*
Netherlands 2	Investigating water problems from space	x	x	x	x								*4*		*x*		x	*x*				-	*3*
Norway 1	Nidelva tour	x	x	x	x		x	x					*6*	*x*		*x*	*x*			*x*		-	*4*
Norway 2	Rainwater retention in urban areas	x	x	x	x								*4*		*x*		*x*	*x*	*x*	*x*		-	*5*
Total		*4*	*4*	*4*	*4*	*0*	*1*	*1*	*1*	*1*	*0*	*1*		*3*	*1*	*4*	*4*	*2*	*1*	*2*	*1*		

[a]Not assessed.

supported the survey data. In one focus group, members discussed the benefits internationalization had for widening their point of view. A Maltese student explained, "It helped to see different practices in different countries". A Czech student added, "So many new ideas and points of view! It seemed to me that I was stuck in the one point of view and didn't see other. It opened my eyes for sure".

Analysis of the lessons

The lessons developed by the pre-services teachers also provide insight into their learning. One Dutch group designed a series of three lessons in which students investigated flood risks in their own environment. Students were subsequently divided into four groups, and each group was connected to a scenario for reducing the flood risks: (1) prevention, (2) flood impact reduction, (3) migration to less flood-prone areas and (4) organised evacuation. Each group had to work out a plan for their scenario, using various resources provided by the teacher.

The second Dutch group designed three lessons in which students investigated water safety issues in different places, using digital maps, satellite images and 360-degree photos. One Norwegian group focused on quick clay landslides, and the question how to control these geohazards. They designed a tour along the Nidelva River in Trondheim with tasks in a fieldwork booklet, using geologic maps, historic maps and geohazard risk assessment maps. A second Norwegian group designed a lesson series on rainwater retention using a Storymap and a virtual walk in the pupils own neighbourhood, using Google Maps and Streetview, make screenshots, add interpretative texts about what can be seen, and share it in a Padlet with the rest of the class.

Table 5 shows the characteristics of wickedness and the wicked problem-solving competencies that are addressed in the lesson series. All four groups paid attention to the complexity of the issue and its connectedness with other issues (characteristics 1 and 2), and to the need for technical solutions as well as societal change (characteristic 3). Every lesson series made clear that the local context mattered (characteristic 4). The other characteristics of wickedness were not addressed, or addressed by one of the four groups. Perhaps these characteristics are more difficult to include in place-based education, or the lesson series were just too short to include more wicked characteristics.

The lessons paid attention to three to six wicked problem-solving skills. The more difficult scenario thinking skills, imaginative thinking skills and skills in reflecting on values were addressed only in the lesson series of the first Dutch group. This lesson series contained a task in which students had to design adaptation solutions themselves, a task at the cognitive level of "creating" according to the revised Bloom Taxonomy. The other three lesson series included elements of exploration, but the boundaries were set. They aimed to stimulate understanding of common adaptation practices, and not so much to develop competencies needed to participate in adaptation. So, in short, the lesson series of the first Dutch group can be seen as an example of "education for wicked problem-solving", while the other three lesson series can be classified as "education about wickedness".

Discussion and conclusion

The EduChange course aimed to equip pre-service teachers from four European countries with the competencies to teach the wicked problem of climate change adaptation. The interdisciplinary international approach and the inclusion of literature research and poster presentation tasks and many fieldwork activities were appreciated by the participants and helped them to develop *Content Knowledge (CK)*. The confrontation with the "otherness" (e.g. France & Haigh, 2018) was valuable for learning, not only because pre-service teachers saw things different from what they knew but also because they were confronted with different perspectives and shared experienced in conversations with each other.

Teaching about climate change adaptation, however, also requires *Pedagogical Content Knowledge (PCK)*. We therefore included a diverse range of workshops in the training week. The pre-service teachers subsequently developed lessons and conducted them in a local secondary school. During reflection week, participants met again and shared their experiences. Surveys and focus group interviews showed that the future teachers were positive about the course, and that it contributed to the development of their PCK. However, contrary to the literature (e.g. Magnusson et al., 1999; Sobel, 2005), the surveys showed that students considered the formal education (lectures, workshops, fieldwork) more important for the development of their PCK than designing, conducting and reflecting on their own education. Perhaps this is because the formal activities were strongly connected to teaching practice, and were characterised by many discussions about the implications, and reflection on experiences.

The four analysed lessons developed by the pre-service teachers addressed between 4 and 7 of the eleven characteristics of wickedness and between 3 and 6 of the eight wicked problem-solving competencies. One of the lessons clearly falls under change-oriented "education for wicked problem-solving", while the other three lessons fall under the knowledge-oriented "education about wickedness".

A big question is whether to address the characteristics of wickedness and the wicked problem-solving competencies implicitly or explicitly in teacher training. As EduChange was a pre-service teacher training course and as the participants were relatively new to teaching, we decided not to overload them and to follow an implicit approach. But for in-service teacher training courses, it might be more effective to choose an explicit approach.

During the EduChange project, the team was confronted with several challenges from conceptual, design and practical nature. Although the practical issues, such as delays from traffic jams, bad weather conditions and the Covid-19 lockdown impacted the program, staff and participants were flexible and worked around such issues. Other challenges lead us to conclude that climate change education can be seen as a wicked problem in its own right (cf. Jordan et al., 2014):

(1) There is no clear definition of what should be the focus of climate change education. There are multiple interpretations about which competencies young people should develop, depending on the point of view.
(2) The problem is characterized by many interdependent components. Climate change education involves not only the wicked problem of climate change itself but also the educational setting (e.g. the curriculum and educational vision of the school), the societal setting (e.g. influence of media, parents and friends on students' perceptions about climate change), and psychological processes such

as distancing and delay discounting. Also, it requires professionalization of teachers – not only the development of CK and PCK but also more general collaboration skills and entrepreneurial skills.

(3) The problem is characterized by interdependencies at different scales. As climate change itself crosses many disciplines, climate change education also requires an interdisciplinary approach. Teachers of different school subjects (with different CK and PCK, including different orientations) should work together. So, climate change education connects the microscale (lesson) and mesoscales (school curriculum). The National Standards (macro scale), which focus on knowledge and not on attitudes, influence climate change education at meso- and microscale.
(4) Climate change education is not connected to one school subject, which makes it difficult to position responsibility.
(5) There is no definite solution to climate change education. As climate change issues evolve, and the educational and societal context is also subjected to changes, educators are forced to focus on a moving target.
(6) There is no single true approach to climate change education. Whether the approach can be viewed as "good" or "bad" depends on one's orientation towards climate change education.
(7) Organizing high-quality climate change education requires not only competent teachers, but rather the synergy between many different stakeholders: teachers, teacher trainers, parents, educational policymakers, local communities, water-boards, climate change researchers, educational researchers, etc.
(8) Attempts to enhance climate change education can lead to broader educational change, for example, towards cross-curricular education and inquiry-based pedagogical approaches, the diffusion of technologies in classrooms, and stronger connections between education and local stakeholders (e.g. communities and water boards).
(9) Such changes can be resisted or encouraged, according to circumstances at the school.
(10) There is no single approach to climate change education. Instead, we can only attempt to fit climate change education with the context.

In the EduChange project, we tried to tackle these challenges and search for a solution that fits the context. The wickedness of the issue prevents a simple copy-paste of EduChange activities to other pre-service education contexts though. However, during the three cycles of designing, testing and evaluating, we developed many ideas on how to train pre-service teachers in teaching climate change as a wicked problem, and we hope that will be explored further and help enhance the education of future teachers.

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References

Arnold, R. D., & Wade, J. P. (2015). A definition of systems thinking: A systems approach. *Procedia Computer Science*, *44*, 669–678. https://doi.org/10.1016/j.procs.2015.03.050

Baerwald, T. J. (2010). Prospects for geography as an interdisciplinary discipline. *Annals of the Association of American Geographers*, *100*(3), 493–501. https://doi.org/10.1080/00045608.2010.485443

Batty, M. (2013). Great planning disasters. In M. Tewdwr-Jones, N. Phelps, & R. Freestone (Eds.), *The planning imagination: Peter hall and the study of urban and regional planning* (pp. 28–39). Routledge.

Blankman, M., Van Der Schee, J. A., Volman, M., & Boogaard, M. (2015). Primary teacher educators' perception of desired and achieved Pedagogical Content Knowledge in geography education in primary teacher training. *International Research in Geographical and Environmental Education*, *24*(1), 80–94. https://doi.org/10.1080/10382046.2014.967110

Bosschaart, A. (2019). *Ecorexia of klimaatapathie? Hoe denken amsterdamse leerlingen over klimaatverandering? Hogeschool van Amsterdam*. Netherlands.

Boyle, A., Maguire, S., Martin, A., Milsom, C., Nash, R., Rawlinson, S., & Conchie, S. (2007). Fieldwork is good: The student perception and the affective domain. *Journal of Geography in Higher Education*, *31*(2), 299–317. https://doi.org/10.1080/03098260601063628

Brew, A. (2012). Teaching and research: New relationships and their implications for inquiry-based teaching and learning in higher education. *Higher Education Research & Development*, *31*(1), 101–114. https://doi.org/10.1080/07294360.2012.642844

Brown, V. A., Harris, J., & Russell, J. (2010). *Tackling wicked problems: Through the transdisciplinary imagination*. Earthscan.

Cantor, A., DeLauer, V., Martin, D., & Rogan, J. (2015). Training interdisciplinary 'wicked problem' solvers: Applying lessons from HERO in community-based research experiences for undergraduates. *Journal for Geography in Higher Education*, *39*(3), 407–419. https://doi.org/10.1080/03098265.2015.1048508

Clausen, S. W. (2017). Exploring the Pedagogical Content Knowledge of Danish geography teachers: Teaching weather formation and climate change. *International Research in Geographical and Environmental Education*, *27*(3), 267–280. https://doi.org/10.1080/10382046.2017.1349376

Davis, S. S., & Thompson, J., S. (2013). Changing the conversation about climate change: A theoretical framework for place-based climate change engagement. *Environmental Communication*, *7*(1), 42–62. https://doi.org/10.1080/17524032.2012.753634

Davis, S. K. (2014). *Communicating climate change through place-based engagement: methods, research, and applications to parks and protected area visitors*. Doctoral dissertation. Colorado State University.

De Wolf, M., Smit, E., & Hurkxkens, P. (2018). *Lesgeven over duurzame ontwikkeling*. derde druk.

Dogan, S., Pringle, R., & Mesa, J. (2016). Professional development in education the impacts of professional learning communities on science teachers' knowledge, practice and student learning: A review. *Professional Development in Education*, *42*(4), 569–588. https://doi.org/10.1080/19415257.2015.1065899

Dummer, T., Cook, I., Parker, S., Barrett, G., & Hull, A. (2008). Promoting and assessing 'deep learning' in geography fieldwork: An evaluation of reflective field diaries. *Journal of Geography in Higher Education*, *32*(3), 459–479. https://doi.org/10.1080/03098260701728484

Dunphy, A., & Spellman, G. (2009). Geography fieldwork, fieldwork value and learning styles. *International Research in Geographical and Environmental Education*, *18*(1), 19–28. https://doi.org/10.1080/10382040802591522

Eurobarometer (2019). Special Eurobarometer Report 490 – Climate change. Directorate-General for Communication. https://ec.europa.eu/clima/sites/clima/files/support/docs/report_2019_en.pdf

Feja, K., Lütje, S., Neumann, L., Otto, K-H., M. L., & Siegmund, A. (2019). Climate changes cities - A project to enhance students' evaluation and action competencies concerning climate change impacts on cities. In L. W. Filho & B. H. L. McGhie (Eds.), *Addressing the challenges in communicating climate change across various audiences,*159–174. Springer.

Fernandez, C. (2014). Knowledge base for teaching and pedagogical content (PCK): Some useful models and implications for teacher training. *Problems for education in the 21rst century 60*, 79–100.

France, D., & Haigh, M. (2018). Fieldwork@40: Fieldwork in geography higher education. *Journal for Geography in Higher Education*, *42*(4), 498–514. DOI:10.1080/03098265.2018.1515187

Gruenewald, D. (2003). The best of both worlds: A critical pedagogy of place. *Educational Researcher*, *32*(4), 3–12. https://doi.org/10.3102/0013189X032004003

Gruenewald, D. (2008). The best of both worlds: Ac critical pedagogy of place. *Environmental Education Research*, *14*(3), 308–324. https://doi.org/10.1080/13504620802193572

Hoffman, J. (2019). Imagining 2060: A cross-cultural comparison of university students' perspectives. *Journal of Future Studies*, *23*(4), 63–78. 10.6531/JFS.201906_23(4).0007

Hope, M. (2009). The importance of direct experience: A philosophical defence of fieldwork in human geography. *Journal of Geography in Higher Education*, *33*(2), 169–182. https://doi.org/10.1080/03098260802276698

Injeong, J., & Bednarz, S. W. (2014). Developing pre-service teachers' Pedagogical Content Knowledge for teaching spatial thinking through geography. *Journal of Geography in Higher Education*, *38*(2), 301–313. https://doi.org/10.1080/03098265.2014.911828

IPCC (2014): *Climate change 2014: Impacts, adaptation, and vulnerability*. Cambridge University Press. https://www.ipcc.ch/report/ar5/wg2/

Israel, A. (2012). Putting geography education into place: What geography educators can learn from place-based education, and vice versa. *Journal of Geography*, *111*(2), 76–81. https://doi.org/10.1080/00221341.2011.583264

Jordan, M., Kleinsasser, R., & Roe, M. (2014). Wicked problems: Inescapable wickedity. *Journal of Education for Teaching*, *40*(4), 415–430. https://doi.org/10.1080/02607476.2014.929381

Karl, H., Curtin, C., Scarlett, L., & Hopkins, W. (2011). Adapting to climate change, a wicked problem: A road map for action. In I. Linkov & T. S. Bridges (Eds.), *Climate: Global change and local adaptation* (pp. 237–254). Springer Science + Business Media.

Kent, M., Gilbertson, D., & Hunt, C. (1997). Fieldwork in Geography teaching: A critical review of the literature and approaches. *Journal of Geography in Higher Education*, *21*(3), 313–332. https://doi.org/10.1080/03098269708725439

Khadka, A., Li, C., Wilhelm Stanis, S., & Morgan, M. (2020). Unpacking the power of place-based education in climate change education. *Applied Environmental Education & Communication, 20*(1), 77–91. https://doi.org/10.1080/1533015X.2020.1719238

Kindon, S., & Elwood, S. (2009). Introduction: More than methods – Reflections on participatory action research in geographic teaching, learning and research. *Journal of Geography in Higher Education*, *33*(1), 19–32. https://doi.org/10.1080/03098260802276474

Kuthe, A., Keller, L., Körfgen, A., Stötter, H., Oberrauch, A., & Höferli, K.-M. (2019). How many young generations are there? – A typology of teenagers' climate change awareness in Germany and Austria. *The Journal for Environmental Education*, *50*(3), 172–182. https://doi.org/10.1080/00958964.2019.1598927

Levin, K., Cashore, B., Bernstein, S., & Auld, G. (2007). Playing it forward: Path dependency, progressive incrementalism, and the super wicked problem of global climate change. In *International studies association 48th annual convention*. Chicago. https://doi.10.1088/1755-1307/6/0/502002

Littrell, M., Tayne, K., Okochi, C., Leckey, E., Gold, A., & Lynds, S. (2020). Student perspectives on climate change through place-based filmmaking. *Environmental Education Research*, *26*(4), 594–610. https://doi.org/10.1080/13504622.2020.1736516

Lopatto, D. (2003). The essential features of undergraduate research. *Council on Undergraduate Research Quarterly*, *24*, 139–142.

Lynch, M. W. (2017). Using conferences poster presentations as a tool for student learning and development. *Innovations in Education and Teaching International*, *55*(6), 633–639. https://doi.org/10.1080/14703297.2017.1286999

Magnusson, S., Krajick, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Kluwer Academic Publishers.

McInerney, P., Smyth, J., & Down, B. (2011). Coming to a place near you? The politics and possibilities of a critical pedagogy of place-based education. *Asia-Pacific Journal of Teacher Education*, *39*(1), 3–16. https://doi.org/10.1080/1359866X.2010.540894

Monroe, M., Plate, R., Oxarart, A., Bowers, A., & Chaves, W. (2019). Identifying effective climate change education strategies: A systematic review of the research. *Environmental Education Research*, *25*(6), 791–812. https://doi.org/10.1080/13504622.2017.1360842

Nundy, S. (2001). *Raising achievement through the environment: The case for fieldwork and field centres*. National Association of Field Studies Officers.

Oost, K., De Vries, B., & Van Der Schee, J. (2013). Enquiry-driven fieldwork as a rich and powerful teaching strategy–school practices in secondary geography education in the Netherlands. *International Research in Geographical and Environmental Education*, *20*(4), 309–325. https://doi.org/10.1080/10382046.2011.619808

Park, S., & Oliver, J. S. (2008). Revisiting the conceptualisation of pedagogical content knowledge (PCK): PCK as a conceptual tool to understand teachers as professionals. *Research in Science Education*, *38*(3), 261–284. https://doi.org/10.1007/s11165-007-9049-6

Pauw, I., & Beneker, T. (2015). A futures perspective on Dutch geography education. *Futures*, *66*, 96–105. https://doi.org/10.1016/j.futures.2015.01.001

Peacock, J., Mewis, R., & Rooney, D. (2018). The use of campus based field teaching to provide an authentic experience to all students. *Journal of Geography in Higher Education*, *42*(4), 531–539. https://doi.org/10.1080/03098265.2018.1460805

Reilly, K., Clavin, A., & Morrissey, J. (2016). Participatory critical enquiry in graduate field-based learning. *Journal of Geography in Higher Education*, *40*(1), 104–116. https://doi.org/10.1080/03098265.2015.1086980

Rittel, H., & Webber, M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169. https://doi.org/10.1007/BF01405730

Roberts, J. T. (2010). Global inequality and climate change. *Society & Natural Resources*, *14*(6), 501–509. https://doi.org/10.1080/08941920118490

Sanders, L. R., Borko, H., & Lockard, J. D. (1993). Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching*, *30*(7), 723–736. https://doi.org/10.1002/tea.3660300710

Savin-Baden, M., & Wimpenny, K. (2007). Exploring and implementing participatory action research. *Journal of Geography in Higher Education*, *31*(2), 331–343. https://doi.org/10.1080/03098260601065136

Scott, I., Fuller, I., & Gaskin, S. (2006). Life without fieldwork: Some lecturers' perceptions of geographical and environmental science fieldwork. *Journal of Geography in Higher Education 30* (1), 161–171. https://doi.org/10.1080/03098260500499832

Shulman, L. S. (1986). Those who understand: Know,ledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. https://doi.org/10.3102/0013189X015002004

Smith, G. (2002). *Place-based Education, Learning to Be Where We Are, Phi Delta Kappan, April 2002*, 584–594. https://doi.org/10.1177/003172170208300806

Sobel, D. (2005). *Place-based education: Connecting classroom and community*. Orion Society.

Termeer, C., Dewulf, A., & Breeman, G. (2013). Governance of wicked climate adaptation problems. In J. Knieling & W. Leal Filho (Eds.), *Climate change governance. climate change management*, 27–39. Springer.

Van Driel, J. H., Verloop, N., & De Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, *35*(6), 673–695.

Weber, E. P., & Khademian, A. M. (2008). Wicked problems, knowledge challenges, and collaborative capacity builders in network settings. *Public Administration Review*, *68*(2), 334–349. https://doi.org/10.1111/j.1540-6210.2007.00866.x

Wilson, H., Leydon, J., & Wincentak, J. (2017). Fieldwork in geography education: Defining or declining? The state of fieldwork in Canadian undergraduate geography programs. *Journal of Geography in Higher Education*, *41*(1), 94–105. https://doi.org/10.1080/03098265.2016.1260098