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Changes in students' knowledge, values, worldview, and willingness to take mitigative climate action after attending a course on holistic climate change education

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ABSTRACT

Though the need for holistic climate change education has been realized around the world, there is a lack of studies that examine the multidimensional impact of climate change education in higher education. To amend for this gap in literature, this paper uses a pre- and post-questionnaire (N = 245) to examine how students' knowledge, values, worldview and willingness to take mitigative climate actions change during a course on climate change. Though the course was designed to be multidisciplinary and holistic, the results show that the course had limited impact. First, the pre-post tests showed a significant increase in science knowledge, but knowledge on mitigative actions remained unchanged despite related course assignments. Second, though participants' worldview seemed to change or strengthen during the course, minimal changes were seen in students' willingness to take mitigative actions. However, an increase in biospheric values -a strong predictor of pro-environmental behavior - was seen in some segments of participants, potentially predicting a lower carbon footprint for those students in the future. Furthermore, the findings suggest that during the course, individuals found new, environmentally friendly ways to address their hedonic pleasures, also potentially having long-term positive effects. Some differences in gender and field of study were noted. Implications of the findings are discussed in relation to planning and implementing holistic climate change education.

1. Introduction

Still today, in many countries climate change education is primarily focused on learning about the science of climate change (Dawson et al., 2022). This can include learning about issues, such as the carbon cycle, greenhouse gases, melting icecaps and feedback-loops (Shepardson et al., 2012; Eilam et al., 2020). However, despite the importance of knowledge, a science-based curriculum approach to environmental issues is inadequate, as it does not prepare students to become active, pro-environmental citizens (e.g. Sterling, 2010).

Therefore, in addition to increasing knowledge, climate change education should encourage students to "re-evaluate [their] worldview and everyday behaviours" *in light of what is* necessary for climate change mitigation (UNESCO, 2017 p. 36). Due to the multifaceted nature of climate change, there is a consensus that education needs to be multidisciplinary, transformative (e.g. (Mezirow, 2003), holistic (Tolppanen et al., 2017) and nothing short of creating a paradigm shift (Kagawa and Selby, 2010). In order to identify the components needed for a more holistic approach to climate change education, Tolppanen et al. (2017) conducted an extensive literature review and developed an educational model on holistic climate change education. The model, later 'road--tested' with experts in the field (Cantell et al., 2019), emphasized that climate change education should aim to (i) increase knowledge, (ii) advance thinking skills, (iii) address values and worldviews, (iv) motivate students to (v) take action, (vi) address emotions, such as hope (vii) create future scenarios of what the world could and should look like and (viii) address the barriers to climate change mitigation. The notion is that if education adheres to the above goals, it has the potential to be transformative. However, though holistic and transformative educational goals have a wide acceptance among the research community, there is no consensus on how they can be reached in practice (see Reid, 2019). Therefore, there is a clear need to examine how such educational approaches can be used effectively in helping advance the challenging educational goals for climate change.

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In this study we examine a course which was developed using state-of-the-art knowhow and pedagogical approaches. The higher-education course, called C*limate.now*, was developed over a one-year period with the help of tens of top climate change experts from various disciplines, such as natural and environmental sciences, environmental engineering, pedagogy and art (see https://climatenow.fi/). A multidisciplinary team of experts was chosen so that some of the dichotomies persistent between different fields could be alleviated (see Lehtonen et al., 2018). The course was planned by using a top-down-bottom-up development approach (see Pietarinen et al., 2017). In practice, this meant that the planning was done in several working groups, in addition to which outside experts were asked to give their input on the content of the course during various workshops. The planning of the course was funded by the Finnish Innovation Fund Sitra, meaning that the experts were paid for committing to the planning process. Once the planning of the course was completed, the course material was made freely available for anyone to use, the material being located at the University of Helsinki MOOC (Massive Open Online Course) platform (mooc.helsinki.fi). Courses based on the *Climate.now* material are currently held in eleven higher education institutions across Finland in the scope of 2–5 ECTS (European Credit Transfer System); 1 ECTS referring to 25–30 h of work required from a student; European Union, 2015). The Climate.now course consists of online learning material at the MOOC platform for independent study, with quizzes to test the learning. While studying the material, students write a learning diary and do assignments related to the reading. Four of the contact sessions with the teacher are designed to be discussive. Students taking the 5 ECTS course also do a project work in groups. The courses have received positive feedback from both staff and students. There is also an active teacher community further developing the course.

In this paper, we examine what type of impact the course has had on the participants, by examining the following research questions:

- RQ 1: How do participants' knowledge, values, worldview and willingness to take mitigative actions change during a multidisciplinary course on climate change?
- RQ 2: Are changes seen in students dependent on their field of study?
- RQ 3: Are changes seen in students dependent on gender?
- RQ 4: Does a potential increase in knowledge or a change in values effect participants willingness to take mitigative action?

By answering these research questions, this study highlights the possibilities and shortcomings of holistic climate change education and gives insight into how climate change education should be improved in order for it to have a greater impact on students' lives.

2. Theoretical framework

2.1. Transformative education and climate action

Transformative education refers to education that develops autonomous and critical thinkers (Mezirow, 2003). In other words, individuals should be willing to examine the foundation that they have built their conceptions on and, if necessary, make changes to their frame of reference. Ideally, in the context of climate change, this will also affect how individuals take action. However, transformative education is challenging, as individuals may not change their views easily, even when presented with compelling scientific evidence (see Hoffman, 2011; Bain et al., 2012).

There are many factors that affect individuals' willingness to take pro-environmental action. As these have been discussed abundantly in other studies, in this paper we will only give a brief overview. Probably most importantly, there is abundant evidence showing that knowledge is not the only factor effecting action (Kollmuss and Agyeman, 2002). Many other factors, such as values (e.g. Steg et al., 2014; Tolppanen and Kang, 2021), attitudes (see e.g. Steg and Vlek, 2009), worldview (Hawcroft and Milfont, 2010), ease of taking action (e.g. Attari et al., 2010) and how risk averse individuals are (Howlett, 2014; Gifford, 2011) are also at play. Especially biospheric values, referring to one caring for the environment, are a strong determinant of pro-environmental behaviors in areas, such as driving and eating habits (e.g. Steg et al., 2014) and carbon footprint (Tolppanen and Kang, 2021).

From a psychological and social perspective, factors, such as norms, moral obligations, societal expectations and, perceived behavioral control also play an important role in action (see e.g. Ajzen, 1991; Gifford, 2011; Steg and Vlek, 2009). Furthermore, individuals also seem to have self-bias and intragroup bias regarding mitigative actions, meaning that individuals prefer low-impact actions for themselves, while preferring higher-impact actions for others (e.g. Sternäng and Lundholm, 2011). Responsibility on high-impact actions may also be deflected on governments and businesses, while individuals see their own role in climate change mitigation as limited (Tolppanen and Kärkkäinen, 2021). Furthermore, factors such as disposable income play an important role in carbon emissions (Enzler and Diekmann, 2019).

Gender may also affect individuals' knowledge, attitudes and willingness to take action regarding environmental issues. For instance, several studies have found that men tend to have higher knowledge on environmental issues (e.g. Hayes, 2001; Eisler et al., 2003; Vicente-Molina et al., 2018), while females may take more pro-environmental actions, at least in some domains of life (e.g. Räty and Carlsson-Kanyama, 2010; Eisler et al., 2003; Vicente-Molina et al., 2018). Furthermore, there may be gender differences in environmental concern, a predictor of pro-environmental action, though findings in this regard are mixed. Several studies have indicated that females show more concern towards the environment than males (e.g. Xiao and McCright, 2015; McCright and Sundström, 2013), though other studies have found there to be no differences (Hayes, 2001; Vicente-Molina et al., 2018), and others that show that males show higher environmental concern, at least in some cultural contexts (e.g. Xiao and Hong, 2010).

Finally, field of study may also affect individuals' ecological worldview and actions. However, findings in this regard are also mixed. For instance, Talay et al. (2004) found that social science students were more interested in environment-related subjects than science students, while Vicente-Molina et al. (2018) found the opposite to be true. Furthermore, when Müderrisoglu and Altanlar (2011) examined differences in different university faculties, they did not find significant differences in attitudes, but found some differences in behavior. These studies indicate that, as with gender differences, findings may be affected by the prevalent culture in different countries.

3. The current study

3.1. Climate.now course to address holistic climate change education

The Climate.now (www.climatenow.fi) course was planned to be a holistic course on climate change, with the majority of the authors of the "holistic climate change bicycle model" (SeeTolppanen et al., 2017; Cantell et al., 2019) in the planning group. To ensure a holistic approach, the planning group also had experts from many different fields, including scientists of atmospheric sciences, forest sciences, climate adaptation, energy technology, educational sciences, as well as artists and experts in communication and digital media. As a result of having a multidisciplinary planning group, the Climate.now course material covers climate change issues from many perspectives. First, students study the scientific basis of climate change (observed climate change, the greenhouse effect, greenhouse gases), functioning of the climate system (the carbon cycle, climate sensitivity and radiative forcing, feedbacks and threshold values), and future of the climate (emission scenarios and climate models, expected changes and uncertainties). Second, students study climate change impacts on ecosystems and human societies. Third, they get to know basics of climate change mitigation (carbon footprint, energy systems, sustainability transformation) and adaptation (measures and policy). Fourth, there are some large topics chosen to study further, namely international climate negotiations, food security and role of forests. In addition to learning the basic knowledge, students learn different competencies in a variety of assignments. For instance, when writing the learning diary, the students learn thinking skills and are encouraged to reflect on their identity, values and worldview, as well as examine their personal motivation and participation in different roles (as a citizen or future expert of a certain field). In project assignments, the students learn action competencies and participation, as well as reflect on possible operational barriers. Some assignments in the learning diary or contact sessions aim at future orientation (like a task to write a letter to your future children) or hope and emotions (Climate change and humanity –video, where the students are brought to think of the big questions of life: birth and death, our different roles and actions we take, as well as values of the society). Students also calculate their own carbon footprint and develop a “carbon diet” for themselves, in which they need to plan how to reduce their personal carbon emissions by 10% each year, for the next 3 years. The expected learning outcomes of the Climate.now course reflect a holistic approach, as presented in Tables 1 and 2.

In addition to being holistic, the aim of the Climate.now course is to be interconnected (see Lehtonen et al., 2018) and transformative (Mezirow, 2003). Interconnectedness is seen in how the course was produced in collaboration with scientists and artists, as well as in how many of the course assignments are created so that they do not only examine the science of climate change, but also require examining emotions, feelings and values through artistic approaches (e.g. assignment to write a letter to future generations). The course aims to be transformative through reflective tasks, as well as through project-works, in which the students can use their creativity to design a feasible plan that has an impact on climate change mitigation. In the course feedback, the students have stated that the project design and especially hearing the other students’ projects has increased their hopefulness and opened their eyes for the opportunities of mitigative climate actions, therefore, being transformative to at least some degree.

Finally, the course aimed to implement educational approaches that have shown to be effective (see Monroe et al., 2019). For instance, students wrote reflective learning diaries, contact sessions were designed to be engaging and discussive, online material included video interviews of top-level scientists, common misconceptions on climate change were addressed in course sessions, and students designed their own projects on a topic related to climate change.

Table 1
Climate.now course learning outcomes and related course activities. The activities chosen for a specific course might vary between universities and courses.

Learning outcome	Activity
Student can examine climate change from many different perspectives and create connections between them, as well as seek for solutions to the climate challenge in a variety of ways.	1. Studying the learning material 2. Reflecting in learning diary 3. Discussing with other students and course teachers 4. Project work
Student can reflect on his or her own role in climate change and apply what has been learned on the course to his or her field of study.	1. Tasks in the learning diary 2. Discussing with other students and course teachers 3. Video interviews on climate change in different fields of the society
Student can examine different perspectives, solutions, information sources and the current debate on climate change critically.	1. Tasks in the learning diary 2. Assignments 3. Discussing with other studentts and course teachers 4. Video material on applied perspectives

4. Method

4.1. Sample and data description

The data for this study was collected through pre-post questionnaires collected during the Climate.now courses held in three higher education institutions in Finland, namely University of Helsinki (UH), LUT University (LUT), and Oulu University (OU). The pre-survey was sent to the students at the beginning of the course and a post-survey after the course. A total of 245 participants answered both the pre- and post-questionnaires and gave permission to use their answers for research purposes. Out of these, 131 were from the UH, 83 from LUT and 21 from OU and 10 did not provide information of which university they are from.

All three universities used the same core material for the course, found at the Climate.now MOOC platform. However, the teachers had the freedom to choose how to implement the actual course. Therefore, the exact content of the three courses, the assignments, and the project that students did during the course varied to some degree. At UH, the course was open to all university students and participants came from various backgrounds. For the majority of them, the course was voluntary, indicating that the participants were already interested in climate change to some extent when starting the course. At UH, the course could be completed as a 2 ECTS or a 5 ECTS (European Credit Transfer System) course. In both cases students were required to complete the online MOOC material, as well as keep a learning diary, which was then graded. In the 5 ECTS course students also had additional assignments, with the main emphasis being on a multidisciplinary group project, in which students designed a climate project. Out of the 154 participating students, 131 answered the questionnaire and gave permission to use their data for research purposes. Out of these, 58 did the 2 ECTS course and 73 did the 5 ECTS course. At LUT, most of the students were engineering students, to whom the course was mandatory. All of the students at LUT did a 5 ECTS course, which included using the Climate.now MOOC material, writing learning diaries and a project where they calculated their own carbon footprint in detail. Out of the 93 participating students, 83 answered the questionnaires and gave consent to use their data for research purposes. At OU the course was open to all university students and participants came from various backgrounds. As the course was voluntary, participants presumably had some level of interest towards climate change issues already at the start of the course. Similar to the UH, in the OU the students could participate in a 2 ECTS or 5 ECTS course. The content was similar to the course held in the UH with the exception that in the 5 ECTS course, students did two group projects, rather than one. A total of 100 students completed the course, but due to challenges in communication regarding data-collection, only 21 students answered both the pre and post questionnaires and gave permission to use the data for research purposes. Out of these, 10 participants did the 2 ECTS course and 11 did the 5 ECTS course.

4.2. Measures

The pre-post questionnaires were identical to each other and consisted of 97 questions (see Table 3). The questionnaire measured four constructs: knowledge, values, worldview and willingness to take climate action. Knowledge was divided into two sub-categories: Scientific knowledge and knowledge of mitigative actions. Scientific knowledge was measured using a previously validated questionnaire, consisting of 21-items (e.g. Libarkin et al., 2018; Aksit et al., 2018). These items measure different aspects of climate change understanding, including historical trends, thermal transfer, sun & radiation, feedback loops and the way greenhouse gases work. Knowledge on mitigative actions was measured using a 19-item questionnaire, developed by Tolppanen et al. (2020). The items examine students’ understanding on the approximate amount of carbon emissions caused by different personal sphere actions, such as flying a long-distant flight or eating a

Table 2
Example of learning activities at a Climate.now course at the University of Helsinki during seven weeks (w1-w7) in year 2020.

		wk 1	w2	w3	w4	w5	w6	w7
		Climate change	Climate system	Future climate	Impacts	Mitigation	Adaptation	Big issues
For all	Joint session	x		x		x		x
	Learning diary	x		x		x		x
	Independent study (MOOC)	x	x	x	x	x	x	x
For 5 cr	Assignments	x	x	x	x	x	x	x
	Group workshop (facilitated by teachers)		x		x		x	
	Group meeting (self-organized)			x		x		x

Table 3
Summary of the measurements used.

What was measured?	Number of items	Range	Where the questionnaire was adopted from?
Values (biosphperic, altruistic, hedonic & egoistic)	16	−1 to 7	Steg et al. (2014)
Ecological worldview (NEP)	15	0 to 5	Dunlap et al. (2000)
Ideologies on climate change	7	1 to 5	Leiserowitz et al. (2013)
Climate change knowledge	21	0 to 21	Libarkin et al. (2018)
Knowledge on climate change mitigation	19	0 to 19	Tolppanen et al. (2020)
Willingness to take mitigative action	19	1 to 5	Tolppanen et al. (2020)

plant-based diet. Values were measured using a 16-item questionnaire, developed by Steg et al. (2014). The questionnaire measures the strength of individuals' biospheric, altruistic, hedonic and egoistic values. Worldview was measured using three different measures. First, the 15-item New Ecological Paradigm scale (NEP), was used (see Dunlap et al., 2000). In addition, 4 items were used to examine students' beliefs on anthropogenic climate change through likert-scale types (e.g. "human activities have no significant impact on climate change") and three items were used to measure students' ideas on humans' ability to mitigate climate change (e.g. "new technologies can solve climate change without individuals having to make big life-style changes"). Five of these items were taken from Leiserowitz et al. (2013), while two were modified from other studies. The fourth construct, willingness to take personal sphere actions, measured willingness to act in seven areas of life (e.g. reducing long-distance flights and eating a plant-based diet), using 19 likert-scale type items. The items in the measurement, developed by Tolppanen et al. (2020), form pairs with the questions on "knowledge of mitigative actions", meaning that it is possible to compare the knowledge and willingness questions with each other on a question-to-question basis. In addition, background information, such as gender, field of study and place of study were collected.

4.3. Data analysis

To investigate the quality of the measurement and to convert nonlinear raw scores to linear scores, we first performed the Rasch analyses with the Winsteps software version 4.8.2. (Linacre, 2021). Compared to classical test theory approaches, often using average values for scoring, the Rasch approach has some advantages as it takes both individual abilities and item difficulties into account in calibrating the scores so that student ability (or agreeability) scores become invariant with respect to items, and vice versa (Boone, 2016). Also, the Rasch techniques use a logit measure which in the end transforms a sum score onto a continuous latent variable as a fixed scale with a mean of 0 and variance of 1 (more detailed methods and results of the Rasch models are presented in Supplementary Material). Accordingly, we conducted the Rasch analyses and generated the person measures from the Rasch models. Thus, results in the main manuscript demonstrate the Rasch measures, while the observed (original) mean values are presented in Supplementary Material, corresponding to each table in the main document. Briefly, according to the Rasch results, all items were acceptable except two items, named CAR4 and HIGHDIET2. Thus, the Rasch person measures of each subscale were extracted except the two items and imported to the SPSS 28 software for further analyses. Then, to examine the pre-post differences, the paired *t*-test was conducted. Also, the independent *t*-test and the analysis of variance (ANOVA) were performed to explore the group differences. Lastly, analysis of covariance (ANCOVA) was used to control pre-test scores and measure group differences in the post-test.

5. Results

5.1. Changes in knowledge, values and worldview (RQ 1)

In order to investigate the impact of the Climate.now course, we compared the pre- and post-questionnaire datasets using the paired-sample test. The findings show that during the course, students' knowledge on climate change increased and the change was statistically significant. A statistically significant change was seen in all faculties (Environmental: $t = -3.63$, $df = 47$, $p < .01$, Natural: $t = -2.11$, $df = 55$, $p < .05$, Technical: $t = -3.53$, $df = 77$, $p < .01$, and Non-STEM, $t = -4.01$, $p < .001$) and in both genders ($t = -5.43$, $df = 135$, $p < .001$ for females and $t = -4.12$, $df = 101$, $p < .001$ for males). When dividing participants into three groups based on their pre-knowledge, the findings show that students with a low-level of pre-knowledge ($n = 67$) and a medium level of pre-knowledge ($n = 118$) showed a significant increase in their knowledge during the course ($t = -8.97$, $df = 66$, $p < .001$ and $t = -4.52$, $df = 117$, $p < .001$ respectively) while those with a high-level of initial knowledge ($n = 59$) indicated a stable level of knowledge ($t = -1.49$, $df = 57$, $p = .14$) (see Fig. 1). Although there continued to be differences in the levels of knowledge between the three groups even

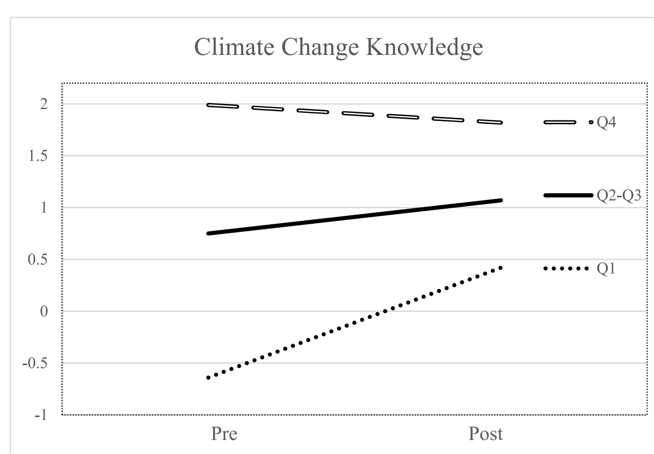

Fig. 1. How climate change knowledge developed over the course depending on starting level (Q1 = 25% worst performers in pre-test, Q4 = 25% best performers in pre-test).

after the course (F = 46.06, df = 242, p < .001), we could conclude that the Climate.now program had a positive impact on the climate change knowledge level especially for those who possessed low level of knowledge before the course.

However, students' knowledge on mitigative actions was low in both the pre and post tests, with no significant increase seen during the course. This could also explain why changes in willingness to take mitigative actions were scarce. When examined as a group, the two aspects in which statistically significant changes were seen were in willingness to change consumption and recycling behavior and use of cars (see Table 4). Moreover, no changes in willingness to take mitigative action were seen in the low-knowledge and high-knowledge groups, while the mid-knowledge group showed a statistically significant increase in willingness to take actions relate to travel (t = −2.45, df = 117, p < .05), car (t = −2.17, df = 117, p < .05) and consumption and recycling (t = −3.23, df = 117, p < .01).

Out of the four values, only biospheric value saw statistically significant increases during the Climate.now intervention (see Table 4), and a closer analysis showed that these results were mainly due to the increase of biospheric value of females (t = −2.56, df = 137, p < .01) (See Tables 4 and 6).

The results also indicate that the course strengthened or changed students' worldview. Though participants mainly believed in human induced climate change and in the possibilities of humans to mitigate climate change prior to the course, these beliefs were increased during the course. Namely, a statistically significant increase was seen in views on anthropogenic climate change (see Table 4). In other words, after the course, students had an even stronger belief that climate change is happening and is human induced.

5.2. Changes seen in students, depending on their major (RQ 2)

To examine whether students' field of study was a determinant on how students' knowledge, values, worldview, and willingness to take action changed during the course, we divided the participants into four groups, based on their field of study: Environmental Science (n = 49), Natural Science (n = 56), Technical Science (n = 75), and Non-STEM such as Business, Social Science, etc. (n = 65). According to the result, as shown in Table 5, most of the differences were found when comparing the Technical Science group to the other groups. For instance, the Technical Science group indicated a lower level of climate knowledge than the other groups, as well as lower biospheric values, altruistic values, and ecological perspectives. Furthermore, they showed higher disbelief and lower motivation towards climate change, as well as lower levels of willingness to take mitigative actions, especially in areas of consumption and recycling, or diet (see Table 5). These differences could be due to the fact that the course was compulsory for most of the students in the Technical Science group, while being voluntary for the other groups. When the pre-test scores were controlled, the only difference between the groups was that the Technical Science group indicated higher level of knowledge on mitigative actions than the Natural Science group (F = 3.96, p < .01, Technical > Natural).

We also examined the difference between pre and post-test within each faculty and found that climate change knowledge increased for all four faculties (Environmental: t = −3.63, df = 47, p < .01, Natural: t = −2.11, df = 55, p < .05, Technical: t = −3.53, df = 77, p < .01, and Non-STEM, t = −4.01, p < .001). In addition, for the Technical Science group, unbelief in anthropogenic climate change decreased (t = −2.04, df = 74, p < .05) and willingness to reduce emissions from travelling (t = −3.01, p < .01) and consumption (t = −2.28, df = 73, p < .05) increased. Also, for the Non-STEM group, hedonic values and willingness to make changes in the lifestyle category increased (t = −2.07, df = 64, p < .01 and t = −2.31, df = 64, p < .05 respectively).

Table 4
Comparison of pre and post test results.

Category	Subcategory	Pre Mean (SD)	Post Mean (SD)	*t*-test
Knowledge	Climate change	0.66 (1.05)	1.07 (0.96)	t (242) = −6.69***
	Mitigative action	−0.92 (0.57)	−0.90 (0.73)	t (243) = −0.36
Value	Biospheric	2.25 (2.19)	2.48 (2.21)	t (244) = −2.36*
	Altruistic	1.36 (1.47)	1.43 (1.41)	t (244) = −1.04
	Hedonic	1.75 (2.57)	1.97 (2.44)	t (244) = −1.79
	Egoistic	−0.84 (0.96)	−0.82 (1.05)	t (244) = −0.39
Attitude	View on anthropogenic CC	−2.85 (1.27)	−3.04 (1.21)	t (243) = 2.64**
	View on humans' role in mitigation	−1.90 (1.6)	−2.04 (1.59)	t (243) = −1.46
	Ecological worldview (NEP)	1.93 (0.67)	1.98 (0.69)	t (244) = −1.52
Willingness	Travel	1.42 (1.63)	1.56 (1.61)	t (244) = −1.89
	Consumption and recycling	3.57 (1.67)	3.83 (1.76)	t (244) = −3.12**
	Car	1.95 (2.58)	2.28 (2.45)	t (244) = −2.21*
	Diet	4.69 (2.71)	4.85 (2.46)	t (244) = −1.34
	Lifestyle	2.18 (1.54)	2.31 (1.56)	t (244) = −1.62
	Energy	1.54 (1.32)	1.61 (1.34)	t (244) = −0.97

*p < .05, **p < .01, ***p < .001.

5.3. Changes seen in students, depending on their gender (RQ 3)

We also investigated the effects of the Climate.now program regarding gender differences. There were 138 females and 102 males in the study. Five students selected their gender as "other, or prefer not to respond". These five students were excluded from the analysis, as the sample size was too small. According to the result, females indicated slightly higher biospheric values and lower egoistic values than males; females were more motivated to mitigate climate change and had a more pro-environmental worldview than males; Also, females indicated higher willingness to take mitigative climate actions in areas of consumption, recycling, diet, and lifestyle. These differences remained after controlling the pre-test score. Specifically, the gender differences were found in view on humans' role in mitigation (F = 8.00, p < .01), ecological worldview (F = 9.30, p < .01), and willingness in consumption and recycling (F = 11.51, p < .01), car (F = 5.85, p < .05), and diet (F = 8.44, p < .01). Furthermore, the pre-post tests showed that males only indicated a statistically significant increase in climate change knowledge (t = −4.12, df = 101, p < .001), while females indicated changes in not only climate change knowledge (t = −5.43, df = 135, p < .001), but also in biospheric values (t = −2.56, df = 137, p < .05), hedonic values (t = −2.48, df = 137, p < .05), view on anthropogenic climate change (t = −5.43, df = 135, p < .001), willingness to mitigate in consumption and recycling (t = −4.22, df = 137, p < .001) and car use (t = −2.48, df = 137, p < .05) (SeeTable 6).

We next constructed multiple regression models including gender and majors in the same statistical model in predicting the six subscales while controlling the pre-data (T1 score) of the corresponding variables as shown in Table 7. These specific subscales were selected based on the ANCOVA results showing that the effects of gender and the majors on the subscales were still significant after controlling the pre-scores. For this, three dummy variables representing environmental science, natural science, and non-STEM majors were created while technical science was used as a reference category for majors since the differences were evident between technical science and other majors. In addition, the effects of biospheric and altruistic values that often indicate high

Table 5
Effect of students Majors on the results (STEM vs Non-STEM).

Category	Subcategory	Pre vs Post	Environmental M (SD)	Natural M (SD)	Technical M (SD)	Non-STEM M (SD)	ANOVA
Knowledge	Climate change	Pre	0.61 (1.17)	1.13 (1.07) [de]	0.44 (0.98) [d]	0.57 (0.93) [e]	F (243) = 5.31**
		Post	1.15 (1.05)	1.39 (0.96) [d]	0.83 (0.85) [d]	1.01 (0.92)	F (243) = 3.97**
	Mitigative action	Pre	−0.92 (0.53)	−0.91 (0.52)	−0.88 (0.61)	−0.98 (0.60)	F (243) = 0.33
		Post	−1.01 (0.66)	−1.11 (0.81) [d]	−0.72 (0.59) [d]	−0.86 (0.80)	F (244) = 3.69 *
Value	Biospheric	Pre	3.23 (1.65) [bc]	2.58 (1.90) [d]	1.52 (2.29) [bd]	2.06 (2.36) [c]	F (244) = 7.14***
		Post	3.31 (2.19) [b]	2.89 (2.06) [d]	1.69 (2.09) [bdf]	2.40 (2.21) [f]	F (244) = 6.58***
	Altruistic	Pre	1.72 (1.15) [b]	1.70 (1.54) [d]	0.90 (1.59) [bd]	1.32 (1.35)	F (244) = 4.68**
		Post	1.81 (1.46) [b]	1.67 (1.52)	1.02 (1.44) [b]	1.41 (1.10)	F (244) = 3.95**
	Hedonic	Pre	1.74 (2.70)	1.79 (2.48)	2.03 (2.56)	1.40 (2.57)	F (244) = 0.71
		Post	1.81 (2.57)	1.88 (2.43)	2.19 (2.69)	1.92 (2.06)	F (244) = 0.31
	Egoistic	Pre	−0.89 (0.88)	−0.91 (1.02)	−0.66 (1.06)	−0.94 (0.85)	F (244) = 1.28
		Post	−0.92 (0.96)	−0.87 (1.15)	−0.66 (1.20)	−0.89 (0.79)	F (244) = 0.87
Attitude	Unbelief in climate change	Pre	−3.04 (1.11) [b]	−2.82 (1.26)	−2.42 (1.44) [bf]	−3.23 (1.01) [f]	F (244) = 5.54**
		Post	−3.30 (1.13) [b]	−2.96 (1.34)	−2.71 (1.31) [b]	−3.30 (0.91)	F (243) = 3.78*
	Unmotivated in climate action	Pre	−2.34 (1.58) [b]	−1.96 (1.53)	−1.44 (1.65) [b]	−2.04 (1.51)	F (244) = 3.66*
		Post	−2.48 (1.70) [b]	−1.92 (1.44)	−1.65 (1.61) [b]	−2.26 (1.51)	F (243) = 3.33*
	Ecological worldview (NEP)	Pre	2.08 (0.61) [b]	2.03 (0.78) [d]	1.68 (0.65) [bdf]	2.02 (0.55) [f]	F (244) = 5.48**
		Post	2.17 (0.85) [b]	1.98 (0.63)	1.75 (0.63) [bf]	2.12 (0.61) [f]	F (244) = 5.12**
Willingness	Travel	Pre	1.61 (1.37)	1.78 (1.87)	1.16 (1.65)	1.26 (1.52)	F (244) = 2.01
		Post	1.71 (1.48)	1.61 (1.62)	1.55 (1.65)	1.42 (1.68)	F (244) = 0.32
	Consumption and recycling	Pre	4.08 (1.47) [b]	3.90 (1.69) [d]	2.99 (1.72) [bd]	3.57 (1.56)	F (243) = 5.52**
		Post	4.27 (1.71) [b]	4.16 (1.63)	3.35 (1.87) [b]	3.77 (1.67)	F (244) = 3.68*
	Car	Pre	2.40 (2.43)	2.06 (2.44)	1.63 (2.60)	1.90 (2.79)	F (244) = 0.92
		Post	2.51 (2.46)	2.33 (2.13)	1.91 (2.58)	2.48 (2.54)	F (244) = 0.87
	Diet	Pre	6.05 (1.16) [ab]	4.66 (2.7) [ad]	3.45 (3.19) [bdf]	5.14 (2.33) [f]	F (244) = 11.29***
		Post	5.87 (1.42) [b]	5.02 (2.34) [d]	3.87 (2.69) [bdf]	5.07 (2.55) [f]	F (244) = 7.56***
	Lifestyle	Pre	2.82 (1.29) [b]	2.40 (1.46) [d]	1.68 (1.59) [bd]	2.08 (1.56)	F (244) = 6.29***
		Post	2.91 (1.49) [b]	2.34 (1.5)	1.79 (1.50) [b]	2.43 (1.58)	F (244) = 5.59**
	Housing	Pre	1.60 (1.31)	1.48 (1.49)	1.47 (1.24)	1.63 (1.28)	F (244) = 0.22
		Post	1.61 (1.30)	1.62 (1.53)	1.61 (1.31)	1.61 (1.27)	F (244) = 0.001

Note. *p < .05, **p < .01, ***p < .001, a Significant difference between G1 and G2. b Significant difference between G1 and G3. c Significant difference between G1 and G4. d Significant difference between G2 and G3. e Significant difference between G2 and G4. f Significant difference between G3 and G4.

correlations with environmentally friendly behavior (Tolppanen and Kang, 2021; Steg et al., 2011, 2014) were controlled. According to the results, similar to the findings that examined gender and majors separately, majors were the significant predictors of mitigative action knowledge, whereas gender predicted ecological perspective, the view on humans' role in mitigation, and the three willingness-related scales (consumption and recycling, car, and diet). Thus, this result indicated that gender and majors may play independent roles in predicting the changes in knowledge, worldview, and willingness to take action.

5.4. How changes in knowledge, value and worldview effected willingness to take mitigative action (RQ 4)

Since the previous results indicated statistical differences in six subcategories—climate change knowledge, biospheric values, altruistic values, hedonic values, belief in anthropogenic climate change, and pro-ecological worldview—we examined whether these positive changes were related to willingness to take mitigative actions using correlation tests. In terms of climate knowledge, both for the pre- and post-test, no correlations were found between knowledge and willingness to take action. That is, although knowledge increased during the Climate.now program, it did not affect participants' willingness to act. Similarly, relationships in belief in anthropogenic climate change and pro-environmental worldview did not have a significant effect on the willingness to take mitigative actions when comparing the pre- and post-test correlation results. Regarding values, the pre-test results indicated some negative correlations between hedonic values and willingness to take action (in Travel, Consumption and recycling, Car, and Diet). However, this correlation disappeared in the post-test results. That is, before the Climate.now course, high hedonic values decreased student's willingness to take mitigative actions but did not do so after the course. This indicates that the participants may try to decouple their hedonic value from their environmental behavior after participating in the Climate.now course.

6. Discussion

Climate change education has been gaining traction in higher education, yet research is scarce on how effective holistic climate change education is. In this study we examined how a holistic course on climate change education, called Climate.now, changed student's knowledge, values, worldview and their willingness to take mitigative actions. A qualitative summary of the findings is provided in Table 8, below.

6.1. Discussing changes seen in knowledge and willingness to act

The findings of this study indicate that a multidisciplinary and holistic course on climate change has a mixed impact on students. First, it was clear that the course showed significant positive changes on student's knowledge on the science of climate change. Furthermore, the level of knowledge at the end of the course was similar to levels of knowledge seen in courses conducted in the US, which did not have a holistic approach (c.f. Aksit et al., 2018). This suggests that regardless of its holistic approach, the course was as effective in teaching climate change knowledge as more traditional courses. Furthermore, the findings show that an increase in knowledge was seen especially among those students who had a poor level of knowledge prior to the course.

Despite the positive gains in climate change knowledge, the results show that knowledge on how to mitigate climate change remained low after the course, and it was not correlated with knowledge on the science of climate change. This finding gives further evidence that it is important to distinguish between different types of climate change knowledge, as has been suggested by several researchers in the past (Frick et al., 2004; Jensen, 2002; Tolppanen et al., 2020). In practice, climate change knowledge should focus on increasing understanding on the science of climate change (see e.g. Shepardson et al., 2012), as well as how climate

Table 6
Differences seen in gender.

Category	Subcategory	Pre vs Post	Female M (SD)	Male M (SD)	*t*-test
Knowledge	Climate change	Pre	0.54 (1.03)	0.80 (1.07)	t (237) = −1.89
		Post	1.00 (0.91)	1.16 (1.03)	t (237) = −1.23
	Mitigative action	Pre	−0.99 (0.53)	−0.83 (0.61)	t (237) = −2.15*
		Post	−0.94 (0.74)	−0.84 (0.72)	t (238) = −1.09
Value	Biospheric	Pre	2.34 (2.03)	1.93 (2.20)	t (238) = 1.49
		Post	2.71 (2.17)	2.03 (2.10)	t (238) = 2.43*
	Altruistic	Pre	1.44 (1.40)	1.22 (1.52)	t (238) = 1.19
		Post	1.55 (1.20)	1.27 (1.51)	t (238) = 1.57
	Hedonic	Pre	1.54 (2.62)	1.90 (2.44)	t (238) = −1.08
		Post	1.93 (2.36)	1.98 (2.57)	t (238) = −0.14
	Egoistic	Pre	−0.99 (0.78)	−0.68 (1.13)	t (238) = −2.40*
		Post	−0.98 (0.75)	−0.68 (1.30)	t (238) = −2.08*
Attitude	Unbelief in climate change	Pre	−3.02 (1.14)	−2.66 (1.37)	t (238) = −2.13*
		Post	−3.23 (1.09)	−2.84 (1.30)	t (237) = −2.48*
	Unmotivated in climate action	Pre	−2.39 (1.48)	−1.26 (1.56)	t (238) = −5.68***
		Post	−2.51 (1.53)	−1.39 (1.46)	t (237) = −5.70***
	Ecological worldview (NEP)	Pre	2.08 (0.69)	1.73 (0.60)	t (238) = 4.17***
		Post	2.17 (0.67)	1.73 (0.66)	t (238) = 5.10***
Willingness	Travel	Pre	1.39 (1.55)	1.45 (1.74)	t (238) = −0.28
		Post	1.57 (1.50)	1.63 (1.75)	t (238) = −0.29
	Consumption and recycling	Pre	3.93 (1.60)	3.12 (1.66)	t (237) = 3.84***
		Post	4.33 (1.56)	3.21 (1.79)	t (238) = 5.15***
	Car	Pre	2.20 (2.49)	1.65 (2.64)	t (238) = 1.66
		Post	2.69 (2.35)	1.77 (2.47)	t (238) = 2.95**
	Diet	Pre	5.66 (1.71)	3.50 (3.10)	t (238) = 6.38***
		Post	5.74 (1.58)	3.67 (2.89)	t (238) = 6.56***
	Lifestyle	Pre	2.43 (1.49)	1.79 (1.51)	t (238) = 3.26**
		Post	2.53 (1.48)	2.01 (1.60)	t (238) = 2.60*
	Housing	Pre	1.63 (1.23)	1.45 (1.34)	t (238) = 1.10
		Post	1.63 (1.27)	1.59 (1.33)	t (238) = 0.23

*p < .05, **p < .01, ***p < .001.

change could be mitigated by individuals and societies. Furthermore, students should understand how these different entities are inter-related and how they need to collaborate with each other in order to reach mitigation targets (Tolppanen and Kärkkäinen, 2021).

Unfortunately, knowledge on how to mitigate climate change remained low even after the course, even though during the course students needed to examine and reflect on their own carbon footprints and develop a "carbon diet" for themselves. This was even the case for students from LUT who did an extensive project on calculating their carbon footprints (worth 3 ECTS). In fact, after the course, the level of mitigative knowledge (6.62 ± 2.7, with a maximum of 21) was so low that students had a 40% chance to get a better than average score only by guessing their answers in the questionnaire. That said, according to the Rasch analyses, the Mitigative Action Knowledge subscale violated some criteria of the Rasch analyses due to the large differences between the participant abilities and test difficulties. That is, the items in the subscale were too difficult to solve for the participants and it might be one of the reasons why the knowledge on the mitigative action was not improved before and after the course participation. Therefore, the scale should be redesigned and refined by reducing the difficulty of the items so that the instrument is well-targeted for the students in question. Furthermore, the scale should be improved so that it would not measure only personal sphere mitigative actions, but also, actions that one might do as a working professional or a social activist. On the other hand, the results do also show that there is a "knowledge gap" regarding mitigative climate actions, and that increasing knowledge on mitigative actions is not an easy task. Therefore, climate education needs to put more emphasis on increasing knowledge on mitigative actions. One possible approach to this could be through games, such as the "1.5 °C Puzzle", in which students need to plan their future carbon footprint during a board game (Nielsen, 2020). Such visual tools and hands-on activities could help bring carbon footprints to a more concrete level, but further research on the effectiveness of such approaches is needed. If proven effective, such research would be useful in helping understand how much of the popular "knowledge-behavior gap" is merely due to a "knowledge gap".

Regarding the knowledge-behavior gap, our results show that such a gap exists at least if knowledge is seen merely as knowledge about the science of climate change. Our results point to this conclusion as participants' willingness to take mitigative actions did not change much during the course, even though their knowledge on the science of climate change did increase. As participants' knowledge on mitigative actions did not increase during the course, it is possible that this is also the reason why changes in willingness to take action were not seen. Despite the fact that in Finland, where this study was conducted, consumption-based carbon footprints are one of the highest in Europe (Ivanova et al., 2015), individuals believe to already live environmentally friendly lives (Lehtonen et al., 2020) and there seems to be an underlying notion that Finland has already done its share in mitigating climate change. Such underlying ideas, combined with a poor understanding of what a carbon footprint consists of, do not make for fruitful ground for behavioral change. Therefore, it is likely that knowledge on mitigative actions is needed in order to see significant changes in willingness to take action.

On another note, already when entering the course, students had a high level of willingness to take mitigative actions. This willingness was higher than in a previous study conducted among Finnish higher education students (see Tolppanen et al., 2020), which could be due to the fact that the Climate.now course was an elective for most of the participants, meaning that a pre-selection had already occurred in who attended the course. The high initial levels of willingness could be another reason why significant changes in willingness to take impactful mitigative action were not seen widely. However, this reason does not seem likely, as participants were willing to change some of their habits, such as their *Consumption and recycling* habits, a type of action that can be considered easy to undertake, though of low mitigative impact (Tolppanen et al., 2020), yet they were not willing to take harder actions, which would have a higher impact (e.g. change travel habits). These findings are in line with previous studies that show that individuals are more inclined to take low-impact actions, while less willing to take high-impact actions (Crosman et al., 2019; Tvinnereim et al., 2017; Tolppanen et al., 2020). However, on a positive note, the technical students, who did an extensive carbon footprint analysis, showed an increased willingness to take actions regarding travelling, which is a

Table 7
Multiple regression model.

	Knowledge		Attitude				Willingness					
	Mitigative Action		Human's role in mitigation		Ecological worldview		Consumption and recycling		Car		Diet	
	B	SE	β	SE	β	SE	β	SE	β	SE	β	SE
T1 score	0.31***	0.08	0.53***	0.06	0.55***	0.06	0.66***	0.05	0.53***	0.05	0.67***	0.05
Biospheric value	−0.02	0.02	−0.09	0.04	0.22***	0.02	0.09	0.04	0.10	0.06	0.09	0.05
Altruistic value	0.06	0.04	−0.01	0.06	−0.06	0.03	0.00	0.06	0.11	0.10	0.03	0.08
Gender	−0.01	0.08	0.11*	0.16	−0.12*	0.06	−0.17***	0.15	−0.12*	0.24	−0.11*	0.21
Majors												
Environmental Science	−0.17*	0.13	−0.03	0.25	0.03	0.10	−0.02	0.23	−0.04	0.38	0.01	0.32
Natural Science	−0.23**	0.12	0.03	0.23	−0.03	0.09	0.01	0.22	−0.02	0.35	0.04	0.29
Non-STEM	−0.07	0.12	−0.04	0.22	0.06	0.09	−0.04	0.21	0.03	0.34	−0.01	0.28

Note. *p < .05, **p < .01, ***p < .001. Values are standardized regression coefficients. All variables are from T2, except for the T1 score. A reference category for majors is Technical Science.

Table 8
Qualitative summary of the aspects of holistic climate education that the climate.now course affected.

Category	Affected areas	changed mainly by	Unaffected areas
Knowledge	Knowledge on the science of climate change	Faculty: All Gender: All	Knowledge on mitigative action
Value	Biospheric	Gender: Females	Altruistic Hedonic Egoistic
Attitude	View on anthropogenic CC	Faculty: Technical Gender: Females	View on humans' role in mitigation Ecological worldview (NEP)
Willingness	Willigness to change consumption and recycling habits	Faculty: Technical Gender: Females	Wililgness to change travel habits ...dietery habits ... lifestyle habits
	... car use habits	Gender: Females	... energy consumption

high-impact action (c.f. Wynes and Nicholas, 2017). This would suggest that extensive analysis of one's own carbon footprint may have a positive effect on behavior.

The fact that after the course participants were willing to make lifestyle changes in *Consumption and recycling* is in line with previous studies (e.g. Crosman et al., 2019; Tvinnereim et al., 2017; Tolppanen et al., 2020) and shows that individuals with higher environmental concern tend to act more pro-environmentally. However, as environmental concerns seem to mainly evoke actions that can be considered low impact (such as consumption and recycling) (see Tolppanen et al., 2020), an increase in environmental concern does not necessarily have a big effect on climate change mitigation. As mentioned, this could be due to the low level of knowledge on mitigative actions. Nonetheless, it is fair to conclude that the Climate.now course failed to make a significant impact on participants personal sphere actions during the course. However, as the study did not examine participants public sphere actions or career-based actions (see Vesterinen et al., 2016), we do not know whether the course had an impact on willingness to take action in these domains. However, other studies suggest that individuals, atleast in Finland, are even less inclined to take public sphere actions than private sphere actions (Harmoinen et al., 2020). Regardless of the negative results, it is important to note that extensive life-style changes take time, and it is possible that willingness to take such lifestyle changes comes with a lag. A follow-up study, conducted a few years after the course, could held understand whether this is the case.

6.2. Discussing changes seen in values and worldview

In order for education to be transformative, it should help students identify and evaluate their worldviews, including their attitudes and values. Furthermore, transformative education should help students change their attitudes and values if these are not aligned with what they have learned and experienced (Mezirow, 2003). As the results of this paper show, Climate.now modified students' values and worldviews, and can therefore be considered to be transformative, at least to some degree. The change in values was especially seen in the non-STEM students and in female students, who showed statistically significant changes in both biospheric and hedonic values. The fact that biospheric values may increase during a single course is encouraging, as biospheric values have previously been shown to be closely linked to environmental behavior (Steg et al., 2014) and carbon footprints (Tolppanen and Kang, 2021). However, the increase in hedonic values during the Climate.now course was somewhat surprising, as hedonic values tend to have a negative correlation with pro-environmental behavior (Steg et al., 2014). Such a negative correlation was seen in the pre-test results, but interestingly, this correlation was no longer seen in the post-test results. This suggests that as knowledge and concern about climate change increased during the course, hedonic values were decoupled from willingness to take mitigative climate action, rather than being suppressed. In other words, after the course, participants no longer thought that taking climate actions and enjoying life are exclusive of each other. This is in line with the findings of Tolppanen and Kang (2021), who postulate that individuals may simultaneously possess contradicting values, such as biospheric and hedonic values, and that such individuals tend to have a low carbon footprint, despite their high hedonic values. Based on their findings, they concluded that the pro-environmental lifestyle that tends to stem from having biospheric values may override the negative effects that hedonic values may have on an individuals' environmental behavior. This hypothesis is contradictory to the assumptions of the authors of the goal-framing theory (Lindenberg and Steg, 2007) who postulate that hedonic values would override other values, not vice versa. Interestingly, the findings of this study suggest that both of these notions should be re-evaluated, as participants don't seem to suppress their biospheric nor their hedonic values. Rather, during the course, students became more aware of their biospheric values, while also uplifting their hedonic values. These findings suggest that during the course, individuals find new, environmentally friendly ways to address their hedonic pleasures, not needing to suppress either biospheric or hedonic values. One limitation we need to consider is that it is possible that after a climate-focused course the students felt an inner pressure to answer more positively to items measuring pro-biospheric values, even though the questionnaire was anonymous. To clarify this, a follow-up study would be needed sometime after the course.

Regarding gender differences, both the pre and post tests showed that females had higher biospheric and altruistic values than males, while males had higher hedonic and egoistic values than females. This is in line with previous studies that have shown that biospheric and altruistic values tend to correlate with each other (Steg et al., 2014) and that females tend to show more of these values (Sargisson et al., 2020). That said, in our study only differences in post-test biospheric values showed statistically significant differences between genders. Therefore, the findings suggest that biospheric values of females are more malleable than those of males, or that the pedagogical methods used in the Climate.now course were more suitable for transforming the values of females than the values of males. All the courses examined in this study had both male and female teachers, so the teacher's gender does not seem to have an effect on these results.

The findings also show that biospheric values were strongest in students studying environmental sciences, while lowest in those studying technical sciences. This difference may be due to the fact that the course was compulsory for the students in technical sciences, while being an elective for those in environmental sciences. This notion is supported by the fact that students in technical sciences also scored lower in other factors of the study (e.g. knowledge etc.). Therefore, in order to clarity whether differences between different fields of study exist, more studies on students with more varied backgrounds are called for.

6.3. Implementing holistic climate change education

The Climate.now course was developed with the idea that it would be a holistic course that all students in higher education could take to become more competent in climate change related issues. However, as this study shows, developing a holistic climate change education course, which meets the fundamental needs of climate change education, is very challenging. Even though the *Climate.now* course was developed by a multidisciplinary group of experts and much time and effort was put into developing the course, the findings of this study show that the course does not sufficiently address all the fundamental issues of climate change education. This was despite the fact that the group of experts planning the course came from many different disciplines, including experts in the science of climate change, mitigation and adaptation of climate change, as well as artists and experts in climate change education (see www.climatenow.fi).

One reason why a holistic approach was not fully achieved could be that when the course planning took place, no models yet existed to guide towards holistic climate change education. Since then, the bicycle model for climate change education has been published to help in this purpose (see Tolppanen et al., 2017; Cantell et al., 2019). Furthermore, a review on effective climate change education has been made (see Monroe et al., 2019) and there is a better understanding of what environmental education should aim for (see e.g. Clark et al., 2020). In the future, similar projects could use these models and other underlying research to reflect on the planning process and to analyze whether some aspects of holistic education should be given more attention. Furthermore, the planning group should have a clear view on how climate change education should not only be multidisciplinary (e.g. science and art), but have a clear idea on how different dichotomies can be combined (see Lehtonen et al., 2018) in order to move from multidisciplinary education towards interdisciplinary education. However, in doing so, they should be aware of the unique characteristics of students in different faculties and gender. For instance, students majoring in science and technical science are likely to possess technocentric worldviews, meaning that they are more inclined to believe in the potential of science and technology in solving environmental issues such as climate change, while students in social sciences may be more interested in learning about the needed societal and political changes. A similar pattern in differences have been found between genders, as males tend to indicate more technocentric attitudes towards environmental problems while females show more eco-centric attitudes (Müderrisoglu and Altanlar, 2011; Tvinnereim et al., 2017). Thus, this kind of perception may make it hard to change the biospheric values of technocentric students during environmental education programs, as shown in our results. Therefore, for the development of climate education, interconnectedness of the biosphere, society, economy, science, and technology, as well as of emotions, mindset, values, and willingness should be well presented and emphasized to make the program more holistic (Lehtonen et al., 2018; Tolppanen and Kärkkäinen, 2021).

As the number of participants and the geographical extent in this study was limited, further studies are needed to examine the effectiveness of climate change education in higher education. As most of the students in our study were already interested in climate change, students with more varied backgrounds needs to be examined and compared to a control group. And most importantly, studies covering longer time spans are needed. Furthermore, this study only consisted of quantitative methods, so qualitative studies are needed to confirm the results of this paper. Finally, it is questionable whether a 2–5 ECTS course, spanning over a few weeks, is sufficient to address climate change holistically, as only a limited amount of content can be included into any given course. Though the course is not perfect, it did show that even a short course on climate change can be transformative to some students and does change their understanding and perceptions of climate change. Furthermore, critical reflection of the course can help to modify the course so that it would become even more holistic. In the context of the Climate.now course, this is done constantly as teachers who held the course in different universities in Finland met regularly to exchange experiences and best practices in teaching and course design. Furthermore, teachers share their materials, such as their learning diary models and model answers to assignments. Also, in collaboration, additional extensions to the course are being produced, transforming it to a more holistic and more international course. Finally, the Climate.now model has been utilized into other online courses, for example *Circular.now* (www.circularnow.fi) on the basics of circular economy, and *Leadership for sustainable change* (www.leadforsust.fi), held under *Climate University* (www.climateuniversity.fi). All of these courses follow the Climate.now principles of open online materials, collaborative teaching and development, multidisciplinary and science-based content and solution-oriented approach.

CRediT authorship contribution statement

Sakari Tolppanen: Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Jingoo Kang:** Validation, Formal analysis, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Laura Riuttanen:** Investigation, Resources, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2022.133865.

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