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What Triggers Climate Action: The Impact of a Climate Change Education Program on Students' Climate Literacy and Their Willingness to Act

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Abstract: There has been an intensive debate in the field of climate change education about what predictors influence youth's climate-related behavior and what educational strategies and practices stimulate such behavior. This study investigated the impact of the 'CO_2 League' program which involved 47 schools (N = 123). For the analyses, we used pre-/-post quasi-experimental design which combined quantitative and qualitative methods: an extensive pre-/-post survey for analyzing several components of students' climate literacy (system/action/effectiveness knowledge, climate change concern, self-efficacy, willingness for climate-protective behavior) and focus group interviews. The analyses revealed a significant impact of sufficient climate change knowledge on climate change concern which subsequently positively influenced participants' self-efficacy and their willingness to act. The findings of this study suggest that knowledge is a key initial driver for climate action, especially for young people, and confirm the conclusion of previous studies that willingness to adopt pro-climatic behavior presupposes a clear and explicit understanding of climate dynamics and its causal relations. The focus group interviews also revealed that the reported increased willingness to act often translated into actual climate action and that learning about the concept of carbon footprint and the process of calculating and decreasing it proved to be a very accessible and fast path to participants' engagement in personal climate action.

Keywords: climate change education; climate literacy; youth's climate action; knowledge–action gap; climate change concern; self-efficacy; willingness to act; climate change behavior model

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1. Introduction

Climate change (CC) is the principal issue of our times with environmental, social, economic, and also educational consequences [1,2], and many researchers [3–9] have emphasized the importance of education as one of the key mitigation strategies. To become a mitigation driver, CCE should incorporate a variety of disciplinary perspectives, translate and frame climate science to be understandable and believable, develop climate literacy, and empower educators and learners, as addressing the climate crisis will require climate literate citizens and students in all segments of the global society [10–16]. While trying to fulfill the complex role described above, CCE research and implementation face several key challenges, concerning the content of CCE, how to best communicate it, and what educational strategies to use. These areas will be crucial for this study, especially the concept of climate literacy, the role of climate change knowledge and attitudes in motivating pro-climatic behavior, and the effectiveness of CCE educational strategies. Our study should bring a contribution to the ongoing CCE discussions by analyzing the impact of a CCE program called the 'CO_2 League' on climate literacy of its participants. The

following sections will summarize the major issues of climate literacy conceptualization and its development.

1.1. Climate Literacy

In recent years, several climate literacy concepts have been proposed [4,17,18] and climate literacy is usually viewed as an intersection of climate science and environmental education approaches and strategies [17,19], as CCE is based on CC scientific concepts and its goal is commonly defined as promoting, stimulating, and cultivating pro-environmental values, attitudes, and behavior [14,19]. In connection with environmental education concepts, climate literacy has been conceptualized in three dimensions–knowledge, competencies (skills), and attitudes or values [4,6,20,21]. However, climate literacy is a relatively new term and its meaning, scope, and content have not been defined and agreed upon worldwide [17]. Most studies dealing with climate literacy have focused primarily on CC knowledge and there is a lack of authoritative definitions of what climate literacy means in all three dimensions.

In the context of the Czech Republic, Miléř and Sládek [17] proposed the system for incorporation of climate literacy (mostly CC knowledge dimension) into Czech school curricula and the Ministry of Environment's panel of experts has recently prepared and published a CCE guide "Klima se mění–a co my?" (The Climate is Changing—What about Us?) [22], which includes brief general definitions of climate literacy for elementary, secondary, and higher education structured in three categories: knowledge, skills, and values/attitudes/behavior.

1.2. CC Knowledge

Within CCE, climate change knowledge has been recently viewed as a complex, multidimensional, and dynamic system, rather than a bulk of climate science facts and concepts [11,23]. This trend is again in accordance with recent environmental education concepts of environmental knowledge [24,25]. Jensen [25], for example, argued that 'environmental knowledge' should refer not only to knowledge about 'effects', but should also include knowledge about 'root causes', 'strategies for change', and 'alternatives and visions'. Similarly, elaborating on Frick et al.'s knowledge structure model [24], Bofferding and Kloser [11] determine and define three domains of declarative CC knowledge—'system knowledge' (mechanistic understanding of climatic system and drivers and impacts of CC), 'action knowledge' (understanding of mitigation actions and behaviors), and 'effectiveness knowledge' (understanding and weighing the potential of particular mitigation activities). According to DeWaters et al. [6] climate science literacy includes 'a broad understanding of climate science, as well as affective (attitudes, values, and self-efficacy) and behavioral attributes related to climate change' [6] (p. 469). Hung [20] adapted Krathwohl's taxonomy of factual, conceptual, procedural, and meta-cognitive knowledge [26] and proposed that they should be realized in three knowledge domains, 'climate change causes', 'climate change impact', and 'climate change management'. Using a slightly different perspective, Azevedo and Marques [4] in their review study utilized three levels of climate literacy knowledge, 'content knowledge' (the facts, concepts, and explanatory theories), 'procedural knowledge' (knowledge of how such ideas are produced), and 'epistemic knowledge' (understanding of the rationale for these procedures and the justification for their use).

1.3. CC Attitudes, Pro-Climatic Behavior, and Knowledge–Action Gap

Many authors stress the importance of climate change attitudes which can strongly influence the willingness to engage in climate action [27–30]. Climate change concern is often cited as one of the driving forces [29,31–34] and there have been large-scale studies that classified students or adults into CC concern categories ranging from alarmed to disengaged or dismissive and explored how the level of CC concern influenced pro-climatic behavior [16,35–37]. Perceived self-efficacy connected to CC mitigation and adaptation is also known as a key determinant, especially for younger people, as the sense of being able

to personally contribute to combating the climate crisis helps them overcome feelings of powerlessness, paralysis, and information overload, and find their own way to personal or community climate action engagement [27,29,38,39]. Finally, constructive hope is considered crucial, most importantly positive hope, based on constructive forms of coping with the threat of climate crisis, as it can provide respite from the harsh reality and give people the strength needed to face the threat, overcome grave emotions, and search for solutions [40–44].

Another key debate in the field of CCE is about what paths lead from CC knowledge to CC concern and climate action, what predictors influence youth's climate-related behavior, and the issue of the knowledge–action gap. Early 'information-deficit' models assumed that if people were well-informed about the causes and consequences of environmental problems, they would adopt pro-environmental behavior [45,46]. However, many subsequent analyses and studies have found the relationship between environmental knowledge and behavior to be less direct and often weak [47], and they have argued that there is a 'knowledge–action gap' [48] and that pro-environmental behavior is shaped through complex interactions between many different factors, such as attitudes, beliefs, social and personal norms, situational and demographic factors, and the influence of social groups and authorities, with knowledge playing only a background role [49,50]. However, in the case of CC, the relationship between variables influencing pro-climatic behavior and the role of knowledge seem to be even more complex and multi-faceted. Some analyses confirm that there is a weak or no correlation between CC awareness/knowledge and the willingness to act in favor of climate protection [51], but other studies have found the link between climate knowledge and behavior to be significant [3,52,53]. Leiserowitz and Smith [36], Stoutenborough and Vedlitz [54], and Guy et al. [55] have found a correlation between higher levels of climate knowledge and concern about CC. Moreover, when climate change knowledge is analyzed in its complexity and different dimensions (as described above), its relationship to pro-climate behavior is shown to be substantial and multi-layered. The impact of mere CC awareness or belief that anthropogenic CC is happening is different from the impact of CC conceptual understanding and understanding of personal actions influence [56]. Action knowledge and effectiveness knowledge have been found to mediate the effect of system knowledge on behavior and are thus considered more directly related to behavior [24]. Action knowledge has been considered to have a greater impact on pro-climate behavior than system knowledge since action knowledge can stimulate behaviors that can be enacted without a full mechanistic understanding of CC and the climatic system. Lack of action knowledge (activities leading to mitigating CC) has been cited by participants of surveys as a major barrier to engaging in mitigating behavior [57–59]. However, Bofferding and Kloser [11] argue that although system knowledge has been shown to have a smaller impact on behavior, the models of a climate literate person still suggest that individuals need to understand foundational concepts of climate science. Analyzing environmental knowledge and behavior, Frick et al. [24] confirmed that system knowledge provides a necessary foundation for action-related and effectiveness knowledge. The interconnection of knowledge dimensions and their impact on pro-climatic behavior seem to get more tangled when we focus on the specific group of teenagers [53].

1.4. Youth's Climate Knowledge and Attitudes to CC

There have been attempts to investigate and analyze youth's climate knowledge and attitudes to CC on a larger scale. In Germany, Kuthe et al. [16] investigated 760 teenagers and identified four groups according to their level of CC awareness (Charitables, Paralyzed, Concerned Activists, Disengaged) which differ in cognitive, affective, and conative aspects of CC. This indicates that young people are not a homogenous group regarding their attitudes to CC. In the US, Leiserowitz, Smith, and Marlon [37] and Roser–Renouf, Maibach, and Myers [60] in their surveys revealed substantial climate change knowledge gaps and misconceptions, and the latter study (1257 teenagers) also analyzed sources of CC information and reported high levels of CC anxiety and only average levels of CC hope

and self-efficacy. In their review study, Corner et al. [61] conclude that today's youth tend to have fairly poor knowledge of CC mechanisms and concepts. However, the levels of climate change concern are generally high among the younger age groups (in some cases higher than in older age groups), and climate concern is usually accompanied by feelings of anxiety, stress, and despair. There also appears to be a lack of self-efficacy among younger people with regard to climate protection.

Similar results have been brought by large-scale studies in the Czech Republic. According to Krajhanzl et al. [62], Czech teenagers see the climate issue as sketchy and haphazard, but also hopeless and frustrating; their self-efficacy with regard to participating in climate protection is very low. Czech teenagers were also—in comparison to other age segments—less willing to adopt everyday domestic pro-climate behavior, but on the other hand more willing to communicate about climate protection. They also declared their willingness to change their lifestyle to help combat CC [62].

1.5. Theory and Practice of CCE

There have been many studies that investigated and proposed effective CCE teaching methods [5,13,14,43,63] and there seem to be several interlinked trends emerging as perspective CCE educational strategies.

Firstly, CCE should be holistic and inter- or transdisciplinary [14,64]. As Kagawa and Selby state [65], CCE should enable learners to view and understand CC from multiple perspectives and help them 'apply cultural, social, economic, ethical, political, and spiritual intelligence to understandings of causes, implications, and proposed ways forward' [65] (p. 241). Regarding school curricula, the CC topic should not be limited to science education and presented as a separate, stand-alone subject area, but it should be integrated across subjects such as science, citizenship education, geography, history, languages, drama, and the arts [66,67].

In addition, CCE strategies and approaches should surpass classroom environment and traditional content delivery, and they should be up-to-date and flexible, student-centered, participative, action and community-based, and enable learners to activate their full potential for climate mitigation and adaptation in a rapidly changing world. Many authors argue that CC, as a complex and multi-disciplinary topic, requires a long-term and multi-layered educational response and they call for utilizing inquiry-based, problem-based, or project-based learning approaches combined with activities stimulating student collaborations, discussions, peer-to-peer interaction, students' autonomy, and non-hierarchical communication, as well as their critical analysis skills for assessing available data and content [5,13,14,65,68–72].

Furthermore, CCE should include both local and global perspectives, interconnecting global processes and context with local consequences, everyday life, and personalized situations [65,73–75]. As Kagawa and Selby [65] argue, climate change education requires a process that embeds learning with action within local community contexts. This can be fulfilled by linking CCE and place-based education which focuses on strengthening place attachment. As results from the study of Khadka et al. [73] show, place-based engagement, situated in a familiar and meaningful context, inspires CC involvement and mitigation. Khadka et al. suggest that 'a hands-on, real-world learning experience, could also help students develop stronger ties to their community, appreciation for the natural world, and heightened commitment to become active citizens' [73] (p. 11).

CCE should also aim at societal and political changes and the solutions to the climate crisis. Therefore, it should move from transmissive towards transformative learning [76] and emphasize learners' empowerment and pro-climate action. Many authors stress the importance of CCE as a driver of societal, economic, and cultural transformations-CCE should focus on strengthening learners' political empowerment and motivating them to participate in pro-climate action, both individual and communal/political [14,77–79]. As noted by Trott and Weinberg [80] (p. 4), it is essential to support learners' ability 'to imagine alternative futures and the kinds of decisions and actions necessary to realize them'.

Finally, CCE should be fully aware that CC and its impacts stimulate a range of strong emotions (especially in young people), which can be very disturbing and overwhelming, e.g., depression, anxiety, sadness, guilt, or denial [42,81]. Thus, one of the key tasks of CCE is overcoming these grave emotions by promoting hope, self-efficacy, and resilience [82–84]. Research suggests that young people feel more hopeful about climate change when they know there are things that they can do personally to address the issue [40–44]. Ojala's studies describe the role of different coping strategies in CCE programs and in order to build self-efficacy and hope they recommend inviting different actors, such as scientists and politicians, into the classroom [40,42–44].

There have been attempts to design and apply multi-layered, action-based and transformative CCE programs-these are long-term programs (often covering the entire school year) aimed at increasing participants' climate literacy such as the 'Youth Climate Challenge' in the USA, 'kidZ21' in Austria [14], or 'Climate Change Before the Court' [85] in Germany. In the Czech Republic, one of the most relevant and successful CCE programs is the 'CO_2 League'.

2. Methods

2.1. The 'CO_2 League' Program Description

The aim of this study was to evaluate the impact of a year-long CCE program 'CO_2 League' on several components of participants' climate literacy in the knowledge and attitudes/values dimensions (system/action/effectiveness knowledge, CC concern, CC hope, and CC self-efficacy) and also their willingness for climate-protective behavior. The investigated constructs were chosen in accord with the program's content, structure, expected outputs, and educational goals which state the pursuit of developing or changing particular climate literacy components. The latest CCE research trends mentioned above were also considered.

The 'CO_2 League' program was created by the Ecological Institute Veronica (a Czech environmental organization that specializes in environmental education) in 2015 and its implementation has been funded by the Ministry of Environment of the Czech Republic. It is a well-known after-school CCE program that has involved hundreds of elementary and high schools. The 'CO_2 League' follows the CCE trends mentioned above in many ways. It is an action-based program that aims at developing students' CC knowledge, strengthening their empowerment and self-efficacy, and stimulating students' climate action and participation. The program is based on the moderate constructivist approach [64,86,87]. It employs project and inquiry-based methods [88–90], and involves place-based and community action activities, autonomous students' teamwork, collaboration and participation, and non-hierarchical interaction of different stakeholders (students, teachers, school management, municipalities, and state administration). Every participating school forms one or more teams of 3–6 students and one teacher tutor (both students and teachers join the teams on a voluntary basis). Each year the program covers a whole school year and includes four missions with several after-school assignments to be completed (the instructions, links, and downloadable materials are shared via the program's website and sent by email). The content of the program's missions is shown in the Table 1.

Table 1. Overview of 'CO_2 League' missions.

Mission	Targeted Climate Literacy Component	Activities
1	CC system knowledge, CC concern	watching videos, reading texts, brainstorming activities, depicting CC through mind maps and art-based activities, sharing results with schoolmates (posters, videos, presenting in front of class, website creation)
2	CC action and effectiveness knowledge (mitigation), self-efficacy, personal climate action	calculating and discussing personal/school carbon footprint, implementing students' ideas to decrease their carbon footprint, sharing results with schoolmates (posters, leaflets, presenting in front of class, team website)
3	CC action and effectiveness knowledge (adaptation), self-efficacy, community climate action	creating an urban 'feeling map' of local areas threatened by drought, heat waves and floods, preparing proposals for adaptation measures
4	CC self-efficacy, CC hope and empowerment, community climate action	interacting with local and national stakeholders, presenting students' mitigation and adaptation proposals to municipality officers, writing to relevant government officials, participation

For the evaluation of the 'CO_2 League' program, the appropriate extent of climate literacy was discussed by the program's authors, climatologists, and educational experts and defined according to the program's content, structure, expected outputs and educational goals. Within the 'CO_2 League' context, a teenage climate literate person (program's participant) was defined as someone who:

- Understands the basic principles of anthropogenic CC and the greenhouse effect;
- Knows the impacts of CC and is able to provide examples of local impacts;
- Knows the major drivers of anthropogenic CC and is able to provide examples of personal everyday activities which contribute to it;
- Knows how effective various ways to combat CC are;
- Understands the principle of carbon footprint;
- Is aware of urgency of implementing solutions to climate crises;
- Believes in his or her own ability to participate in combating CC and succeed in it (self-efficacy);
- Is willing to participate in activities which will most likely help to combat CC (on the personal, community and political level).

This study presents findings from in-depth analyses of the 'CO_2 League' program and it explores the following research questions:

1. What was the impact of the 'CO_2 League' program on participants' climate literacy components (investigated constructs) and also their willingness to engage in climate action?
2. Are any of the investigated constructs (system/action/effectiveness knowledge, CC concern, self-efficacy) significantly related to participants' willingness to act?
3. Do other predictors (gender, age, elementary/secondary interface) have a significant relation to participants' willingness to act?

2.2. Data Collection

The investigation of 'CO_2 League' utilized a quasi-experimental research design [91,92] and combined quantitative and qualitative methods within a mixed method approach [91–93]. Quantitative data were collected through pre-/post-test in the form of an online survey. The survey included 43 multiple-choice items (offering responses on the Likert scale) and two open-response items. It was divided into 5 sections which investigated different constructs:

1. What is global warming/CC? (5 items, system and action knowledge);

2. How much will the following activities help us mitigate CC? (10 items, effectiveness knowledge);
3. Is CC a serious problem? (8 items, CC concern);
4. What do you think about the following statements? (7 items, CC mitigation self-efficacy);
5. Are you willing to adopt the following actions to help mitigate CC? (8 items, willingness to act)

The structure of the survey was designed according to the program's climate literacy definition and the research questions. The wording of some survey items was loosely based on several previous studies [11,13,42,52,94,95] and it was validated through several rounds of revising and consulting with the program's authors, education experts, and climatologists. The survey's reliability was verified by Cronbach's alpha tests (see Table 2 below), and it was pilot tested on two pilot groups (N = 45), which led to final adjustments (for full wording of the survey's items see Supplementary Materials). The collection of quantitative data was fully anonymous.

Table 2. Survey structure and Cronbach's alpha test results.

Survey Dimension	Number of Items	Cronbach's Alpha
System knowledge	3	0.57
Action knowledge	2	0.55
Effectiveness knowledge	10	0.67
Knowledge (aggregate)	15	0.79
Concern	8	0.80
Self-efficacy	7	0.79
Willingness to act	8	0.73

The qualitative data were collected after the program's conclusion through interviews with 6 student focus groups (N = 27) and 6 teachers [91,92]. Focus group participants were randomly selected from 'CO_2 League' participants who completed all four assigned missions. The interviews with focus groups and teachers were conducted online, and they were recorded, transcribed, and coded. Transcriptions were analyzed according to thematic analysis [96]. The interview design involved ten questions concerning students' and teachers' perceptions of the program, and also students' evaluation of their climate literacy and climate action development (for full wording of the interview items see Supplementary Materials). The collection of qualitative data was fully anonymous. The participants had the opportunity to refuse to participate in the research, and in the case of student focus groups, parental consent was required.

2.3. Data Analyses

Quantitative data from the online survey were analyzed using SPSS Statistics (IBM SPSS Statistics for Windows, version 28.0. IBM Corp.: Armonk, NY, USA). Hypotheses were tested against a 5% significance level, $\alpha = 0.05$. The *t*-test was used to compare two groups, with effect size calculated using Cohen's d. Correlations were determined by calculating Pearson's correlation coefficient. Open-ended items were analyzed according to thematic analysis [96].

Theoretically-based models were developed to test the relationships between the observed dimensions. Building on previous studies [11,24,52,97–99] and considering the data analyses results, we determined system, action, and effectiveness knowledge as the exogenous variables and CC concern, CC self-efficacy, and willingness to act as endogenous variables. We based our models on the climate change behavior model proposed by Stevenson [52], which we modified and expanded, using Bofferding and Kloser's [11] three-dimensional CC knowledge concept. We hypothesized that all knowledge dimensions would predict CC concern and action knowledge would additionally predict self-efficacy and willingness to act. CC concern and self-efficacy were proposed as intervening variables for willingness to act.

The validity of the models was verified using structural equation modeling in SPSS Amos 27 Graphics. The indices for model fit recommended by Hu and Bentler [100] were observed. A summary of these follows, with the ideal cutoff values for a good model in parentheses [100]: χ^2, the comparative fit index (CFI, >0.95), Tucker–Levis index (TLI, >0.95), goodness of fit index (GFI, >0.95), adjusted goodness of fit index (AGFI, >0.95), root mean square error of approximation (RMSEA, <0.06), and standardized root mean squared residual (SRMR, <0.08). The strength of the relationship between model elements is represented by standardized regression weights and interpreted as follows: <0.1 small effect, 0.11–0.25 medium effect, >0.25 large effect.

2.4. Participants

This study investigated participants of the 2020/2021 year of 'CO_2 League'. The pre-test was completed by all participating teams—47 teams from schools from the Czech Republic (N = 429, seventh–ninth graders from elementary schools and secondary school students, 12–17 years old), of which 21 teams (N = 188) finished all four assigned missions and completed the post-test. Pre- and post-test responses were matched according to anonymous students' personal codes. Due to missing or mismatching personal codes, the final sample size was reduced to N = 123. The participating schools were from various parts of the Czech Republic and included schools in rural areas, small towns, and big cities, see Table 3 below.

Table 3. Socio-demographic characteristics of participants (N = 123).

Characteristics	Group	N	%
Gender	girls	70	56.9%
	boys	53	43.1%
Age	12 years	7	5.7%
	13 years	21	17.1%
	14 years	26	21.1%
	15 years	28	22.8%
	16 years	31	25.2%
	17 years	10	8.1%
School type (nth grade)	elementary school (7.)	26	21.1%
	elementary school (8.)	23	18.7%
	elementary school (9.)	28	22.8%
	secondary school (1.)	34	27.6%
	secondary school (2.)	10	8.1%
	secondary school (3.)	2	1.6%
Rural area/Town/City	rural area	32	26%
	town	51	41.5%
	city	40	32.5%

3. Results

The result section is structured according to the research questions stated above. The results of the survey data analysis are followed by qualitative data findings (focus group interviews), which often expand on the survey results.

3.1. RQ1: The Impact of 'CO_2 League' Program on Participants' Climate Literacy Components and Their Willingness to Engage in Climate Action

The results from the quantitative data analyses show statistically significant mean increases between the pre-test and post-test for all of the investigated variables. The mean increases for the knowledge dimensions were considerably more significant than increases for CC concern, self-efficacy, and willingness to act (see Table 4).

Table 4. Summary of paired-samples *t*-tests for investigated scales.

Variable	M_{pre}	SD_{pre}	M_{post}	SD_{post}	*t*	Cohen's d
System knowledge	1.16	0.63	1.48	0.65	−5.31 **	0.48
Action knowledge	0.70	0.45	0.87	0.45	−4.06 **	0.37
Effectiv. Knowledge	6.54	1.14	6.98	0.128	−3.64 **	0.33
Knowledge (aggregate)	8.40	1.28	9.32	2.01	−5.43 **	0.49
Concern	4.00	0.63	4.13	0.63	−2.84 *	0.26
Self-efficacy	3.48	0.70	3.61	0.74	−2.38 *	0.22
Willingness to act	3.69	0.74	3.78	0.67	−2.05 *	0.19

Note: * $p < 0.05$; ** $p < 0.001$.

These findings were consistent with data obtained from focus groups. During the interviews, students (and teachers) unanimously confirmed the positive impact of the program and reported numerous ways the program increased their climate literacy, apart from generally contributing to their life (improving teamwork, communication, and interpersonal skills).

The respondents accentuated substantial improvement of CC system knowledge—many of them claimed no or very poor conceptual understanding of CC. They appreciated having the chance to grasp CC in their own way through project-based activities and autonomous teamwork, to clear up their misconceptions, and to become fully aware of the CC human dimensions and the extent of the problem. This led to their heightened CC concern and awareness of the importance of human action to address climate change.

> The main thing is that we learned about how to solve these problems and what they originated from. (Student 2, team F)

> Now, for example, we talk about it more at school, we are concerned about it more than ever before. (Student 3, team F)

Both the students and teachers especially acknowledged learning about the concept of carbon footprint and various ways of decreasing one's footprint (action and effectiveness knowledge). Prior to the program, few participants had heard about a 'carbon footprint' or thought about the impact of their behaviors and everyday decisions. Due to the participation in the program, they felt well-informed and motivated to make a difference (and to decrease their personal carbon footprint).

> I think it was great that they had the chance to think for the first time about what carbon footprint is and how they can reduce it, to present it to the whole class. Later the boys told me that they had talked to their parents at home about whether it was necessary to use two cars and other similar things. (Teacher A)

> Calculating the carbon footprint was something new for the students and also very surprising. (Teacher D)

Furthermore, the respondents confirmed that the program motivated them to engage in various pro-climatic action. Following the program, many participants reported that their daily routines had changed. Common themes were saving energy, minimizing or recycling waste, sustainable shopping, or preferring walking, cycling, and using public transport over using cars.

> After we did the mission with the CO_2 calculator, I started to try harder and take public transport and also eat homemade food. We also try not to throw away food at home and not to use disposable plastic packaging. (Student 3, team A)

> Our whole family has become more environmentally friendly-for example, we have started eating less meat or driving less. (Student 2, team C)

> I try to recycle more waste, or buy second-hand things, or reduce eating beef and eat more chicken meat, for example. (Student 4, team D)

Beyond engaging in personal pro-climatic behaviors, students declared sharing knowledge acquired during the program with their class and schoolmates. This was supported by the design of the program's assignments which included presenting their results to class or schoolmates through posters, leaflets, presentations in front of class, or team websites/Instagram channels. Sharing knowledge with schoolmates was often perceived as one of the most enjoyable activities of the program. Students also mentioned engaging family and community members and confirmed the "ripple effect" of the program beyond the school context and into family and community settings. Most commonly, students advocated behaviors that save energy, decrease consumption, minimize waste, or decrease burning fossil fuels.

> I also really enjoyed presenting some things from 'CO_2 League' to the others in the class. We tried to tell them what 'CO_2 League' was about, what was important-a lot of our classmates then told us that they started thinking about it, at least a little bit. (Student 2, team A)

> I liked that I could do something that would affect others, I could inform the whole high school about something important. (Student 2, team E)

> I am glad that I persuaded my family to save more at home, for example save electricity or water. (Student 3, team A)

Finally, the students also appreciated that the program introduced them to larger-scale CC mitigation and adaptation measures, motivated them to extend their climate action engagement beyond personal actions and enabled them to participate in school or municipal planning. Presenting students' proposals and interacting with school and municipality officials were viewed by many students as very stimulating and influential.

> The last mission, when we wrote to the Minister of Environment, I rewrote the email two or three times before I was satisfied, it was definitely interesting. (Student 1, team A)

> The meeting with the mayor was very stimulating. (Student 1, team B)

> I learned that there are not only solutions for individuals, but that much more can be done at the community level. (Student 2, team D)

> Before the program, they didn't communicate much, so the benefit was the development of communication, they learned to search for data, they found out how newspapers were edited, they walked around, took pictures, they became interested in their surroundings. (Teacher B)

3.2. RQ2: The Relation of the Investigated Constructs to Participants' Willingness to Act

3.2.1. Correlation Analyses

The results of correlation analysis are presented in Table 5. Participants' system, effectiveness and action knowledge dimensions are only weakly or moderately correlated to self-efficacy and willingness to act (rs range from 0.15 to 0.27, respectively, from 0.14 to 0.26). It is worth noticing that when the three knowledge dimensions are compared, it is action knowledge which has the strongest correlation to self-efficacy and willingness to act.

Table 5. Correlations between scales.

	Age	System Knowledge	Action Knowledge	Effectiveness Knowledge	Knowledge (Aggregate)	Concern	Self-Efficacy
Age							
System knowledge	0.12						
Action knowledge	0.14	0.63 **					
Effectiveness knowledge	0.09	0.47 **	0.52 **				
Knowledge (aggregate)	0.13	0.77 **	0.76 **	0.91 **			
Concern	−0.07	0.24 **	0.36 **	0.38 **	0.40 **		
Self-efficacy	−0.02	0.25 **	0.27 **	0.15	0.24 **	0.63 **	
Willingness to act	−0.06	0.14	0.26 **	0.18 *	0.22 *	0.66 **	0.61 **

Note: * $p < 0.05$; ** $p < 0.01$.

On the other hand, there is a significantly much stronger positive relationship between knowledge dimensions and CC concern (rs range from 0.24 to 0.40, $p < 0.01$), indicating that an increasing level of system, effectiveness, and action knowledge about CC may be associated with an increasing level in CC concern.

The correlation analyses also show that there was a very strong positive correlation between increasing concern and self-efficacy, and similarly between increasing concern and willingness to act, suggesting that increasing participants' concern about CC (reinforced by improved CC knowledge) may lead to participants' heightened self-efficacy and willingness to act. As the results in Table 5 show, there is also a very strong correlation between increasing self-efficacy and willingness to act.

3.2.2. Structural Model Building

Structural equation modeling method was used for further exploration of the CC knowledge–concern–self-efficacy–willingness to act interrelationships and multiple models of various complexity were fitted to estimate the magnitude and relationship among the variables. All model modifications were theory-guided and considered the CCE literature review conclusions discussed above and the survey/focus group interviews analyses results.

Model 1, presented in Figure 1, was obtained with $\chi^2 = 8.15$, $p = 0.148$, DF = 5; GFI = 0.98; AGFI = 0.91; TLI = 0.97; CFI = 0.99; RMSEA = 0.072; SRMR = 0.033 fit indices values.

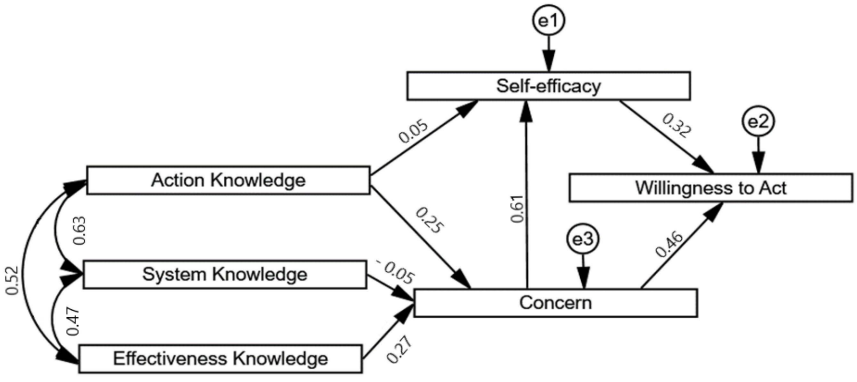

Figure 1. Model 1.

Although Model 1 fitted the data adequately and supported most hypothesized prediction paths, action knowledge was not found to be a significant predictor of self-efficacy (β = 0.05) and system knowledge was not proved as a positive predictor of CC concern (β = −0.05). The testing of proposed models indicated that willingness to act is not affected directly by CC knowledge; therefore, this path was omitted from the model. As was hypothesized in correspondence with previous studies, data analysis results, and calculated correlations, we found that CC concern was a quite strong predictor of self-

efficacy (β = 0.65) and both CC concern and self-efficacy were significant predictors of willingness to act (β = 0.46, respectively β = 0.32).

After testing further modifications, we also proposed Model 2, presented in Figure 2, which was obtained with $\chi^2 = 1.722$, $p = 0.89$, DF = 5; GFI = 0.99; AGFI = 0.98; TLI = 1.04; CFI = 1; RMSEA < 0.0001, SRMR = 0.019 fit indices values.

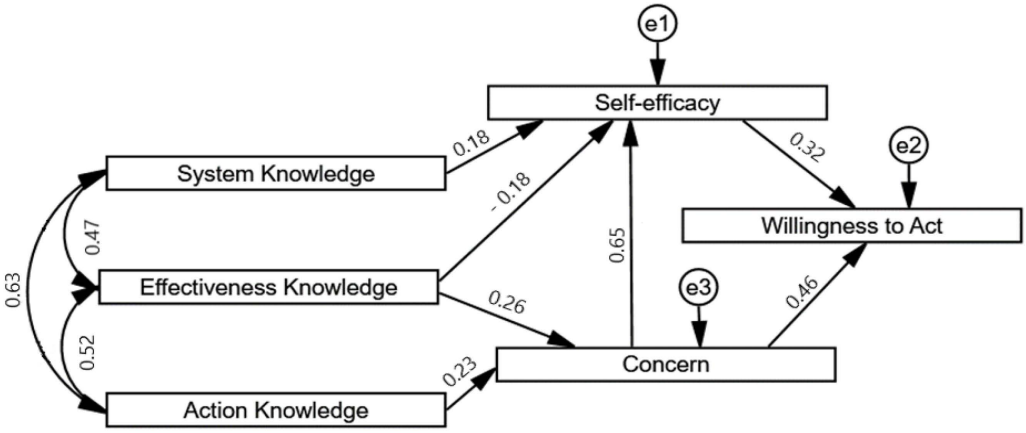

Figure 2. Model 2.

In Model 2, we proposed a direct prediction path from system knowledge to self-efficacy and it proved significant (β = 0.18). Effectiveness and action knowledge were found to be significant positive predictors of CC concern (β = 0.26, respectively β = 0.23), but effectiveness knowledge was actually proved as a significant negative predictor of self-efficacy (β = −0.18). CC concern again predicted self-efficacy (β = 0.65) and both self-efficacy and CC concern remained significant predictors of willingness to act (β = 0.46, respectively β = 0.32), as in Model 1.

The results of the structural equation modeling suggest that there was a significant but rather complex causal link between participants' CC knowledge gains and higher CC concern and self-efficacy, and subsequently higher CC concern and self-efficacy stimulated their willingness to act.

3.3. RQ2: The Relation of Other Predictors (Gender, Age, Elementary/Secondary Interface) to Participants' Willingness to Act

The analyses of survey data show that girls exhibited significantly higher levels of CC concern and willingness to act than boys (in both pre-test and post-test), but there was no significant difference between girls and boys with regard to CC knowledge and self-efficacy (see Table 6). This corresponds with many previous studies which report females' higher level of environmental attitudes [3,101–107]. Regarding CC concern, the 'CO_2 League' program very likely impacted girls more than boys and heightened girls' CC concern more significantly, and the *p*-value changed from 0.024 (pre-test) to 0.009 (post-test).

No significant correlation between age and the investigated constructs was found (see Table 5). It can be assumed that if the sample was larger (e.g., thousands of participants), participants' CC attitudes and their willingness to act would decrease with increasing age, as has been confirmed by studies investigating environmental attitudes of adolescents [108–110].

Additionally, no significant differences between upper-elementary and secondary students within their CC concern, self-efficacy, or willingness to act were found (see Table 7). However, we found out that upper-elementary students were significantly less knowledgeable about CC in the pre-test than secondary students. Younger students lacked mainly CC system knowledge, which means they were less sure about the mechanisms of climate change in the pre-test. However, the difference in knowledge was much smaller and not statistically significant in the post-test, which indicates that participation in the 'CO_2 League' program most likely enabled upper elementary students to gain important

CC (mainly system) knowledge and erased the knowledge difference occurring in the pre-test (see Table 7).

Table 6. Gender differences.

Variables	M_{girl}	SD_{girl}	M_{boy}	SD_{boy}	*t*	Cohen's d
System knowledge PRE	1.08	0.63	1.26	0.61	−1.59	0.289
System knowledge POST	1.48	0.65	1.48	0.67	−0.05	0.010
Action knowledge PRE	0.67	0.44	0.76	0.46	−1.11	0.202
Action knowledge POST	0.90	0.48	0.82	0.40	1.04	0.190
Effectiveness knowledge PRE	6.40	1.16	6.72	1.09	−1.58	0.287
Effectiveness knowledge POST	7.00	1.18	6.94	1.41	0.242	0.044
Knowledge (aggregate) PRE	8.14	1.89	8.73	1.73	−1.796	0.327
Knowledge (aggregate) POST	9.38	1.94	9.25	2.10	0.37	0.067
Concern PRE	4.11	0.54	3.86	0.70	2.28 *	0.415
Concern POST	4.27	0.50	3.95	0.74	2.67 *	0.512
Self-efficacy PRE	3.58	0.69	3.35	0.69	1.83	0.334
Self-efficacy POST	3.71	0.72	3.48	0.75	1.70	0.310
Willingness to act PRE	3.94	0.62	3.37	0.76	4.55 **	0.829
Willingness to act POST	3.98	0.63	3.51	0.63	4.05 **	0.737

Note: * $p < 0.05$; ** $p < 0.001$.

Table 7. Elementary (ES) and secondary school (SS) differences.

Variables	M_{ES}	SD_{ES}	M_{SS}	SD_{SS}	*t*	Cohen's d
System knowledge PRE	1.04	0.57	1.34	0.67	−2.65 *	−0.495
System knowledge POST	1.47	0.68	1.50	0.62	−0.216	−0.040
Action knowledge PRE	0.66	0.45	0.78	0.44	−1.525	−0.284
Action knowledge POST	0.87	0.43	0.87	0.47	−0.001	0.000
Effectiveness knowledge PRE	6.42	1.15	6.73	1.11	−1.492	−0.278
Effectiveness knowledge POST	6.91	1.15	7.08	1.48	−0.708	−0.132
Knowledge (aggregate) PRE	8.12	1.83	8.86	1.78	−2.208 *	−0.411
Knowledge (aggregate) POST	9.25	1.93	9.45	2.15	−0.522	−0.097
Concern PRE	3.97	0.54	4.06	0.75	−0.824	−0.154
Concern POST	4.18	0.50	4.05	0.81	0.917	0.191
Self-efficacy PRE	3.52	0.69	3.42	0.72	0.729	0.136
Self-efficacy POST	3.68	0.71	3.49	0.77	1.378	0.25
Willingness to act PRE	3.75	0.70	3.60	0.79	1.141	0.213
Willingness to act POST	3.82	0.65	3.71	0.70	0.913	0.170

Note: * $p < 0.05$

4. Discussion

This study was designed to test the impact of the 'CO_2 League' program on participants' CC knowledge, CC concern, CC self-efficacy, and their willingness to engage in pro-climatic behaviors. The results show that the program most likely improved their CC understanding, increased their CC concern and self-efficacy and motivated them to engage in climate action. The results also strengthen evidence that well-planned and well-conducted CCE programs, which follow modern CCE trends described in the Introduction section, improve climate change literacy of their participants. This is consistent with other studies that evaluated impact of similar long-term CCE programs, such as 'kidZ21' [14] or 'Climate Change before the Court' [85].

4.1. 'CO_2 League' Strengths

The analyses of quantitative data and focus group interviews reveal several effective strategies employed by the 'CO_2 League' program which correspond with the contemporary CCE trends mentioned above and most likely contributed to the positive impact of the program on the participants.

Firstly, the program covers a whole school year which gives participants enough time to grasp the complex CC topic [5], improve their CC knowledge, develop their CC attitudes, and engage in climate action, while employing the 'head, hands, and heart' principle introduced by Sipos, Battisti, and Grimm [21]. Secondly, the program is embedded in the school environment, which provides necessary equipment and enables participants to get together, plan and organize activities. But the program also motivates participants to go beyond this environment, engage with their communities and experience climate action in real-life situations. The student-centeredness of the program is another of its strengths. As noted by Trott and Weinberg [80], CCE programs can cultivate a sense of agency that combats climate change anxiety and withdrawal, when they engage young people using participatory approaches and treat them as decision-makers and collaborators throughout the process of learning and action. The program also effectively employs the carbon footprint concept which provides an accessible and fast path to participants' engagement in personal climate action. The program purposefully motivates participants to share knowledge and experience acquired during 'CO_2 League', contributing to the 'ripple effect' of the program. As the participants confirmed during focus group interviews, shifting from being recipients of CC content to becoming CC communicators strengthened their self-efficacy and their empowerment. Besides that, sharing knowledge was very often felt as enjoyable and stimulating. Finally, the program enables participants to interact with various stakeholders (school management, municipal, and state administration officers) and participate in community projects, local climate action, and municipal planning. As many previous studies confirm, such interaction and engagement contribute to the cultivation of the youths' political voice and their political empowerment, they help them overcome climate change anxiety and other grave feelings and prepare them to become 'future leaders' of climate crisis solutions [14,42–44,77–79]. However, children and young people are still under-engaged in climate change dialogue and action and overlooked as agents of change within their families and communities [84].

4.2. The Role of CC Knowledge and CC Concern in CCE

In correspondence with Czech and foreign surveys and studies [61,62,111], this study implies that young people have a very low and sketchy CC knowledge. They lack knowledge of causal relations within the climate system, and they are not aware of their role as 'causal agents' within climate change and its mitigation [111]. As the results show, the 'CO_2 League' program helped its participants to correct this deficiency and gain sufficient understanding of climate mechanisms and their own personal role in them. This seems to be crucial for building climate action potential. The results of this study supports previous studies [11,111] which argue that the willingness to adopt pro-climatic behavior presupposes a clear and explicit understanding of climate dynamics and its causal relations and that there is a certain threshold level of CC knowledge that needs to be reached to trigger a behavioral response. Taquier and Pongiglione [111] call for knowledge where individual causality is clear and explicit, and that acquiring some practical knowledge on the impact of daily actions on the environment may allow people to help prevent climate change. Although our proposed model did not show a direct causal link between CC knowledge and willingness to act, in consistency with previous studies [24,52,66] sufficient CC knowledge proved to be a key initial driver which enhances CC concern. CC concern subsequently mediated knowledge–self–efficacy and knowledge–willingness to action relationships. This confirms what recent studies and models suggest: sufficient knowledge leads one to feel concerned, and subsequently being concerned leads one to feel more self-efficacious [29,31,33]. Corresponding with previous studies [29,31–34], our results and their analysis also show the crucial role of CC concern and the causal link which leads from heightened CC concern to enhancing CC self-efficacy and willingness to engage in climate action.

4.3. Models of Paths to Pro-Climatic Behavior

As the proposed models show, this study adds a new perspective to developing a theoretical model of climate change behavior among adolescents that links knowledge, concern, self-efficacy, and behavior, and highlights a need to accommodate this framework within climate change education [52]. Our study also confirms the conclusion of previous studies [11,24] that CC knowledge is a complex and multi-faceted construct and a three-dimensional CC knowledge concept (system, action, effectiveness knowledge dimensions) represents CC knowledge significantly better than a general knowledge construct. The three-dimensional concept should be applied when CC knowledge is analyzed as a predictor of CC attitudes and pro-climatic behavior, as it enables more detailed and accurate analyses. Previous studies confirm that action knowledge and effectiveness knowledge have been found to mediate the effect of system knowledge on behavior and are considered more directly related to behavior [24] and action knowledge has been considered to have a greater impact on pro-climate behavior than system knowledge. However, in contrast to the mentioned studies and to what we expected, the models proposed by this study imply a different role of system knowledge, which proved to be significantly related to self-efficacy. We also found that action and effectiveness knowledge were not significantly linked to CC self-efficacy, but they significantly predicted CC concern. This might be caused by the particular knowledge content of the program and the definition of what system, action, and effectiveness knowledge actually contain. In the case of the 'CO_2 League' program, system knowledge included learning about the concept of carbon footprint. As the focus group interviews revealed, only a few participants had heard about a 'carbon footprint' prior to the program and they really appreciated learning about it. They reported that it enabled them to think about the impact of their behaviors and to realize that they can make a difference. Moreover, focus group interviews showed that acquiring system knowledge about their individual role in the causal mechanisms of CC often translated into engaging in climate action. The second reason might be that 'CO_2 League' content and assignments interlinked system knowledge with personal and local contexts and enabled participants to learn about the causes and effects of CC in their surroundings. The importance of providing personal and local perspectives in CCE programs is supported by many previous studies [65,71,73–75]. On the other hand, action and effectiveness knowledge included general information about human activities which help mitigate CC, and it was presented at the early stage of the program from a global perspective. This might have enhanced the contribution of action and effectiveness knowledge to increasing CC concern.

4.4. Implications for CCE and Future Studies

This study raises a few interesting questions for future studies. The findings presented above suggest that sufficient CC knowledge is one of the key initial drivers for climate action (crucial for increasing CC concern and self-efficacy), especially for young people, whose CC knowledge is very sketchy and who need to grasp an understanding of climate dynamics and its causal relations. This means there is a certain information deficit and it needs to be overcome. This does not mean that enabling young people to understand the mechanisms of CC and their role in it is enough—learning about CC mechanisms must be accompanied by activities strengthening youth's self-efficacy, building constructive hope, and providing opportunities to engage successfully in personal and community climate action. Further research should investigate how the model of climate change behavior among adolescents that links knowledge, concern, self-efficacy, and behavior can be translated into effective formal and non-formal CCE programs. Our study also suggests that more research with larger and more representative samples should be focused on the nuanced interrelations and roles of system, effectiveness, and action CC knowledge and their complex relationships to CC concern, CC self-efficacy, and willingness to engage in climate action. Furthermore, the question of what system, action, and effectiveness knowledge should actually contain to help design effective CCE programs requires more

investigation, as well as utilizing the concept of carbon footprint in CCE as an effective means to engage young people in climate action.

4.5. Limitations

Some limitations of this study have to be mentioned. First, there was no control group to compare the results of the intervention with students who did not participate in the 'CO_2 League'. Secondly, our analyses included only a limited set of variables and did not cover other important factors which might influence willingness to participate in pro-climate actions, such as social and personal norms, worldview, situational factors, and the influence of social groups and authorities. As the survey applied in this study did not control for these additional influencing factors, the significant mean increases in participants' CC knowledge and CC attitudes cannot be unambiguously attributed to the 'CO_2 League' intervention. Another limitation of this study is that the participants joined the' CO_2 league' program on a voluntary basis, which means they do not represent a random sample because it is likely that they arrived with a certain amount of interest in the program's content and motivation to engage in climate action. This raises doubts about the external validity of the presented findings. Whether the findings will replicate outside the program and whether students without initial interest and motivation will also experience the program's positive effects, is a question for future research. However, the mixed-methods approach enabled measuring the program's impacts in multiple ways, and focus group interviews served to clarify and elaborate on survey findings, while allowing participants to specify behavioral changes motivated by their participation in the program. An additional limitation is that post-program focus group interviews took place soon after the program ended, so the long-term impacts of the program are unknown, including whether and to what extent participants' behavioral shifts were sustained over time. Finally, within the statistical analysis of quantitative data, it is necessary to interpret the results in the light of the lower reliability of some of the knowledge scales, mainly due to the small number of items.

5. Conclusions

This study explored the multi-level impacts of the 'CO_2 League' program on its participants' CC knowledge, CC concern, CC self-efficacy, and their willingness to engage in climate action. One important conclusion is that the program significantly improved their CC understanding, increased their CC concern and self-efficacy and motivated them to engage in climate action. Another important result is that the statistical analysis of the quantitative data revealed the crucial and complex role of CC knowledge which needs to reach a certain threshold level to become a key driver for enhancing CC concern and CC self-efficacy (mediated by CC concern). We also found out that the 'CO_2 League' participants were inspiring action and sharing knowledge with others around them, including friends and family as well as in school and community settings.

The results also strengthen evidence that well-planned and well-conducted CCE programs, which follow modern CCE trends, improve climate change literacy of their participants, and develop their potential to make well-informed decisions, take relevant climate action, and be future leaders of finding solutions to climate crisis.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su141610365/s1, S1: Online survey and Focus group interview (full wording).

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