Teaching Typically Achieving Students and Students With Learning Disabilities About the Science Underlying Climate Change

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Abstract

This research evaluated the implementation of a climate science curriculum intervention for students in Grades 4 and 5, including those who were typically achieving and those with difficulties in mathematics, reading, or both. Pre- and posttests of measurement and climate change science concepts were administered at the beginning and end of each study. Study 1 consisted of 69 students in the control group (three classes) and 74 students in the treatment group (four classes). Study 2 included 50 students in the control group (three classes) and 46 students in the treatment group (three classes). Compared to Study 1, the curriculum was significantly modified in Study 2 to incorporate more interactive and arts-based activities. Dichotomous and continuous analysis approaches were conducted. Overall, the results of the analyses indicated that students in the treatment group, regardless of whether they had any learning difficulties, improved significantly in their understanding of the scientific concepts underlying climate change and global warming.

Keywords: Climate change, curriculum intervention, mathematics skills, reading skills, STEAM (science, technology, engineering, arts and mathematics)

Ensuring that all citizens have scientific literacy is crucial to understanding and solving pressing issues in our rapidly changing world (Turiman et al., 2012). In particular, ensuring students have sufficient and accurate climate change science learning can encourage lifelong pro-environmental behaviors and actions (Porter et al., 2012). However, often the basic science underlying climate change is not properly taught in K-12 classrooms, so misconceptions about basic climate science are being conveyed (Lambert et al., 2012; Monroe et al., 2017; Porter et al., 2012).

Prior Studies

Monroe et al. (2017) reviewed English-language, peer-reviewed literature in EBSCOhost, and found 959 unique citation records matching their criteria for climate change education, but despite the importance of educating young people, only 49 studies involved education interventions to teach climate change. Moreover, out of the 49, only nine articles noted children in K-5, highlighting the paucity of research with younger children.

The major findings of the nine studies identified by Monroe et al. (2017), which were conducted in various parts of the world, are briefly reviewed in the following. For example, Baker and colleagues (2013) in Nova Scotia, Canada, found misconceptions of Grade 4 (48 students, two classes) in pretesting but demonstrated that art-based teaching improved student understanding. Hallar et al. (2011) in Colorado, United States of America (USA), provided a place-based, meteorological science mentorship experience to students in Grade 5 and 6 (more than 200 children), with posttesting showing increases in climate science literacy. Similarly, Jin et al. (2013) assessed Grade 4 to 12 students (more than 600 students) in the midwest-

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ern USA using a curriculum intervention; posttesting showed that students made gains in understanding carbon-transforming processes but lacked the ability to do higher-level experimentation. Further, Karpudewan et al. (2015) in Malaysia used a quasi-experimental design to examine how Grade 5 primary students' (11-year-olds) attitudes and knowledge of climate change were influenced by a science curriculum. Their findings showed that attitudes favorable towards environmental stewardship and increased knowledge of climate change were higher in the treatment group than the control group.

Leigh (2009) administered a curriculum with energy reduction related to climate change in more than 60 elementary schools, in Norfolk, United Kingdom, and noted a 19% energy use reduction across participating schools. Lester et al. (2006) implemented a curriculum intervention in five elementary schools in the USA, which increased the students' scientific knowledge and propensity towards social activism. Mason and Santi (1998) evaluated the impact of collaborative discourse with respect to the greenhouse effect, delivered to 22 Italian school children in Grade 5, and found increased metacognition and knowledge revision as a result of the intervention. In another study with 25 teachers and 75 students, as part of a climate change training program, Pruneau and colleagues (2006) noted behavior change of both teachers and their students. Finally, in Crete, Zografakis et al. (2008) found that 321 students and their parents modified their behavior in response to understanding energy use.

The above examples illustrate that it is possible to teach the fundamental science concepts underlying climate change to children and can lead to positive action. Such teaching can help correct science literacy misconceptions that would otherwise, if left unchecked, continue into adulthood (Lambert et al., 2012).

A further study of the literature involving a Web of Science Core Collection, Clarivate Analytics (WOS), search on October 9, 2023, using the terms "climate change" or "global warming" AND "teaching" resulted in 2,062 entries from 1994 to 2023. When narrowing research down to articles and reviews only, this analysis resulted in 1,775 (1,618 articles, 107 reviews, 67 early access, 49 editorials). Of these, a smaller subset related to the preschool to Grade 7 level, and K-12 more generally.

To date, few studies have involved learners in Grades 5 or lower (primary); most are university or high school, with some at the middle school level. Supporting this, in a systematic review, Nepraš et al. (2022) found that usually youth studied with respect to climate change teaching were older, at least 11 years old. Overall, previous studies on climate change teaching have neglected younger children, and none of them have focused on children with disabilities.

The Present Study

Promoting science literacy should focus on creating inclusive curricula that allow for all students to learn fundamental science concepts (Brigham et al., 2011). Learning scientific concepts can be challenging for many students, in particular those with learning disabilities (LD), who, as a result, often fall behind their typically achieving peers (Asghar et al., 2017; Brigham et al., 2011; Lynch et al., 2007). Despite the challenges, however, it is important for these students to understand the science underlying pressing issues, such as climate change, to be fully informed and active citizens in the 21st century.

To this end, we studied a two-part climate change curriculum intervention with children in Grades 4 and 5 (9- to 11-year-olds) and assessed both typically achieving students and students with learning difficulties in mathematics, reading, or both. Study 1 used the basic curriculum, whereas the curriculum in Study 2 integrated more interactive and arts-based methods.

Study 1

Participants

A total of 155 students, 125 in Grade 4 and 30 in Grade 5, participated in the study, from seven classes recruited from six elementary schools in Vancouver and North Vancouver, BC, Canada, with three control and four treatment classes. Of that number, 143 students met the criteria for inclusion in analyses given completed testing and categorization into typically achieving or students with LD. The mean age was 116 and 120 months for control and treatment groups, respectively. Given the purpose of this study to investigate whether children with LD can benefit from the instruction as well as typically achieving peers, both typically achieving and students with LD in mathematics, reading, or both were identified. Dichotomous and continuous methods were used to define learning disabilities.

Design

Classes were assigned to control or treatment groups. Treatment classes received the climate change curriculum intervention. Control classes received the standard science and mathematics curriculum of British Columbia Canada. Pretests were administered for Measurement Knowledge (MK), Climate Science Knowledge (CSK) and reading and mathematics. Posttests for MK and CSK were given 1-3 weeks after the curriculum intervention ended.

Curriculum Intervention Instruction

Instruction was given to classes of 25 to 30 students from February to May once a week in 40- to 60-minute periods based on the regular classroom teachers' schedules. By the time the posttest was administered, classes in the treatment group had received instruction for four sessions. These interventions were given by a research assistant in collaboration with each classroom teacher.

The major goal of the curriculum was to develop students' science literacy. In Study 1, only part of the full curriculum was delivered due to time constraints. Topics addressed in this curriculum, which was more measurement heavy than Study 2, were the following: area, volume, perimeter, use of rulers, matter, solids, liquids, gases, molecular movement, heat, energy, and kinetic-molecular theory. The curriculum was delivered using PowerPoint presentations and hands-on activities, with most of the explanations being oral or visual rather than textual. Children were encouraged to ask questions throughout.

Scientific literacy is an evolving combination of science-related attitudes, skills, and knowledge. After the curriculum, it was expected that students would understand basic concepts in multiple disciplines and would be able to use the vocabulary to describe climate change and its impact on the earth. This kind of instruction was intended to form a foundation upon which students could build a more sophisticated scientific understanding; increased instruction early on helps reduces misconceptions later in life (Stein & Raudenbush 2013).

Testing of the Curriculum Intervention

Climate Science Knowledge

Measurement of Climate Science Knowledge (CSK) predominantly focused on state changes of matter (using a test adapted from Nancy Stein, unpublished). The CSK test covered states of matter, molecular structure, and global warming and consisted of true or false questions, multiple-choice, and short-answer questions. Graduate research assistants marked the short-answer questions together and reached close to 100% agreement. The internal reliability coefficient was 0.81 for the pretest and 0.90 for the posttest (a random selection of 100 tests from the entire sample).

Measurement Knowledge

Measurement knowledge (MK) covered basic math, including perimeter, area, and volume, and used multiple-choice and short-answer questions. Three graduate research assistants marked the short-answer questions together and reached agreement. The internal reliability coefficient was 0.84 for the pretest and 0.86 for the posttest (a random selection of 100 tests from the entire sample).

Reading and Mathematics Skills

Testing of skills included measures of decoding, word identification, vocabulary skills, and mathematics achievement. These measures were used to divide students into groups of different achievement levels.

Work Attack Decoding

For decoding skills, the Word Attack test from the Woodcock-Johnson III Tests of Achievement (Woodcock et al., 2001) was used. Word Attack is an individually administered test that assesses the ability to sound out pseudowords (e.g., "mell," "loast").

Word Identification

For word identification skills, the Word-Letter Identification test from the Woodcock-Johnson III Tests of Achievement (Woodcock et al., 2001) was used. The test requires the child to read aloud real words that increase in difficulty (e.g., "is" in lower levels, "precipitate" in higher levels).

Vocabulary

For vocabulary skills, the vocabulary section of the Group Reading Assessment and Diagnostic Evaluation (GRADE, level 4; Williams, 2001) test was used. The test consists of multiple-choice questions in which the child is required to specify the appropriate meaning of a given word that each student read silently. The internal reliability coefficient was 0.88.

Mathematics Achievement

The Iowa Tests of Basic Skills Math (ITBS Math; University of Iowa College of Education, 2001) GRADE level 4 was used to measure math achievement in areas such as estimation, problem solving, and computational skills. The internal reliability coefficient was 0.92.

Data Analysis

Learning performance (LP) was treated as dichotomous (LD/typically achieving) and continuous in separate analyses. In the dichotomous approach, students' skills were measured for reading and mathematics. Students scoring below the 25th percentile rank on Word-Letter Identification, Word Attack, or Vocabulary were defined as having reading skills difficulty. Similarly, students who scored below the 25th percentile rank on ITBS Math were defined as having mathematics skills difficulty. Due the constraint of sample size, we did not distinguish types of LD in the analysis. Students who performed at or better than the 35th percentile rank threshold in all the measures were defined as typically achieving. Students who had LD in reading and/or mathematics skills were compared to typically achieving students in CSK and MK. A three-way ANOVA, Time*LP*Instruction, was conducted for CSK and MK separately. The analysis was performed using the rstatix package in the R platform (Kassambara 2023).

In the continuous approach, linear mixed-effect modelling was employed to examine the instructional effects on CSK and MK and the moderating effects of reading skills and mathematics skills. Reading and mathematics skill effects were estimated separately. Two models were built for each outcome. Model 1 examined the moderating effect of reading skills, and Model 2 examined the moderating effect of mathematics skills. The two models were otherwise identical, containing fixed effects of time (pre- vs. posttest), group (control vs. treatment), and moderating variable (reading or mathematics skills). There also were tests for two-way interaction between time and group, the two-way interaction between time and moderating variable, the two-way interaction between group and moderating variable, and the three-way interaction between time, group, and moderating variable. Individual participant was set as random intercept. The model was estimated using the algorithm of full information maximum likelihood. The analysis was performed using the lmer test package (Kuznetsova et al., 2017) in the R platform (R Core Team, 2023).

Results

The Dichotomous Approach

Table 1 shows descriptive statistics results on pre- and posttests for CSK and MK.

Climate Science Knowledge. A three-way ANOVA was conducted to compare the main effects of treatment, LP (learning performance: LD vs. typically achieving), and time (pre- vs. posttest) as well as their interaction effects on CSK. The results showed a significant main effect of LP on CSK, $F(1, 146) = 42.17$, $p < 0.05$, indicating that the CSK of students with LD were lower than that of typically achieving students. In addition, time also had a statistically significant effect on CSK, $F(1, 146) = 55.68$, $p < 0.05$, with students' performance increasing across time. When treatment group was considered with time, a significant two-way interaction effect was found on CSK, $F(1, 146) = 15.43$, $p < 0.05$. Also, the interaction effect between LP and time on CSK was significant, $F(1, 146) = 9.50$, $p < 0.05$.

Table 1

Percent Correct for the CSK and MK Pre- and Posttest, for Students With Learning Difficulties (LD) and Typically Achieving (Typical) Given Control and Treatment Groups in Study 1

	Climate Science Knowledge			Measurement Knowledge	
	N	*Mean*	*SD*	*Mean*	*SD*
Pretest					
Control, LD	21	17.2	4.59	28.2	15
Treatment, LD	28	17.2	7.26	19.9	9.04
Control, Typical	46	27.2	10.9	36.5	11.3
Treatment, Typical	55	21.6	9.35	27.7	11.3
Posttest					
Control, LD	21	18.6	7.12	33.1	18.7
Treatment, LD	28	24.5	7.67	30.1	10.1
Control, Typical	46	32.9	13.5	41.8	16.3
Treatment, Typical	55	36.9	13.9	41.9	15.5

A paired sample *t*-test was conducted to compare the differences in pre- and post-CSK scores of students with or without LD in control vs. treatment groups. The results indicated that students with LD in the treatment group attained significantly higher scores after receiving climate change curriculum instruction, $t(27) = - 4.42$, $p < 0.05$, whereas students in the control group, who did not receive the curriculum intervention, did not improve across time. In contrast, significant differences were found in CSK scores of typically achieving students in the control group, $t(45) = -3.11$, $p < 0.05$, and in treatment group, $t(54) = - 8.73$, $p < 0.05$, indicating both groups of typically achieving students demonstrated improvement in CSK in the posttest.

Measurement Knowledge. Significant main effects were found for treatment, $F(1, 146) = 5.57$, $p < 0.05$; LP, $F(1,146) = 18.43$, $p < 0.05$; and time $F(1, 146) = 64.82$, $p < 0.05$. Students in the treatment classes showed greater improvement in MK than those in the control classes. Typically achieving students performed at a higher level in MK than those with LD, and their MK scores increased from pre- to posttest. Furthermore, the results revealed a significant interaction effect of treatment and time on MK, $F(1, 146) = 10.79$, $p < 0.05$.

A paired *t*-test was performed to assess the differences in pre- and post-MK scores of students with or without LD in control vs. treatment groups. The results indicated that there was a significant difference in MK of typically achieving students in both the control and the treatment group, with control group posttest MK scores significantly higher than those in the pretest, $t(45) = 2.88$, $p < 0.05$, and a significant difference in treatment group pre- and posttest MK scores, $t(54) = -8.32$, $p < 0.05$. A significant difference was also found for students with LD in the treatment group, $t(27) = -5.19$, $p < 0.05$, but not for the control group.

The Continuous Approach

The estimated fixed effects in the models are shown in Table 2. The fixed effects in Model 1 ex-

Table 2
Fixed Effects in Linear Mixed-Effect Models Predicting Climate Science Knowledge (CSK) and Measurement Knowledge (MK) in Study 1

Model Parameters	CSK		MK	
	Est. (SE)	*t*	*Est. (SE)*	*t*
Model 1				
Intercept	22.59 (1.40)	16.14***	32.60 (1.76)	18.53***
Exp vs. Con	-2.13 (1.85)	-1.15	-7.05 (2.32)	-3.04**
Pre vs. Post	3.88 (1.47)	2.65*	5.08 (1.58)	3.21**
Reading	0.25 (0.09)	2.94**	0.24 (0.11)	2.25*
Exp*Post	8.90 (1.93)	4.60**	7.25 (2.09)	3.47**
Exp*Reading	-0.12 (0.11)	-1.14	-0.08 (0.13)	-0.63
Post*Reading	0.10 (0.09)	1.06	-0.01 (0.10)	-0.10
Exp*Post*Reading	0.02 (0.11)	0.19	0.00 (0.12)	-0.03
Model 2				
Intercept	22.93 (1.16)	19.80***	32.48 (1.32)	24.57***
Exp vs. Con	-2.32 (1.55)	-1.5	-6.45 (1.76)	-3.65**
Pre vs. Post	3.94 (1.36)	2.89*	4.74 (1.49)	3.17**
Math	0.37 (0.07)	5.19***	0.54 (0.08)	6.66***
Exp*Post	9.00 (1.82)	4.94***	8.09 (1.99)	4.06**
Exp*Math	-0.03 (0.11)	-0.25	0.03 (0.12)	0.20
Post*Math	0.16 (0.08)	1.96*	0.12 (0.09)	1.32
Exp*Post*Math	0.16 (0.13)	1.24	0.11 (0.14)	0.81

Note. Con = control group; Est = estimate; Exp = experimental group; Math = mathematics skills; Post = posttest; Pre = pretest; Reading = reading skills; *SE* = standard error; *t* = t-value.

plained 25.2% of the variance in CSK and 17.8% of variance in MK. The fixed effects in Model 2 explained 44.2% of the variance in CSK and 49.7% of the variance in MK.

Is instruction effective in improving children's climate science knowledge and measurement knowledge? The interaction terms between group and time were significant on CSK (Model 1 Estimate = 8.90, $p < 0.01$; Model 2 Estimate = 9.05, $p < 0.01$) and MK (Model 1 Estimate = 7.25, $p < 0.01$; Model 2 Estimate = 8.09, $p < 0.01$), indicating that students in the treatment group made significantly greater gain than those in the control group in the two outcomes at the posttest. In addition, the contrasts between pre- and posttests were also significant (all $p < 0.05$), meaning both groups of children improved in CSK in the posttest.

Do reading and mathematics skills influence gains from the instruction? For reading, the moderation effect was tested by the three-way interaction between time, group, and reading skills. The results in Model 1 showed none of the three-way interaction effects were significant. However, the fixed effects of reading skills were significant on both outcomes (both $p < 0.05$), meaning that the reading skills were associated with the initial level of CSK and MK.

For mathematics, the moderation effect was tested by the three-way interaction between time, group, and mathematics skills. The results in Model 2 showed that none of the three-way interaction effects were significant. However, the fixed effects of mathematics skills were significant on both outcomes (both $p < 0.05$), indicating that mathematics skill ability was associated with the initial level of CSK and MK. Additionally, the interaction between mathematics skill and time was also significant on MK ($p < 0.05$), suggesting that children with higher mathematics skills made more gains in CSK across time ($p < 0.05$).

Discussion

We found that Grade 4 and 5 students were able to understand the basic scientific concepts underlying climate change and global warming. This finding parallels the literature. For example, Karpudewan et al. (2015) studied Grade 5 children (aged 11 years old) using a quasi-experimental design, in which a treatment group (n=55) with learner-focused climate change activities was compared to a control group (n=60) with more traditional teaching methods to assess the learners' knowledge of climate change and attitudes as well as whether a relationship between knowledge and attitude existed. This research showed that both knowledge and attitude increased in the more interactive presentation of the treatment group compared to the control group.

We also found that both typically achieving and students with LD were able to acquire these concepts. Pfeifer and colleagues (2023) noted that there are barriers to learning science, technology, engineering and mathematics (STEM) subjects, but active learning can help students with learning difficulties, including specific learning disabilities and attention-deficit/disorder (ADHD). These researchers found that some active learning strategies worked in undergraduate STEM classrooms whereas others posed barriers for students, especially less structured activities. Our study with Grade 4 and 5 children used more structured active learning, which was reported as being more effective by the undergraduates in the Pfeifer et al. (2023) study, suggesting that future teaching of STEM with primary school, and also older, learners with learning difficulties, could benefit from the inclusion of properly scaffolded active learning instruction.

Our results show that even students without learning difficulties benefitted from explicit instruction of MK in primary school-aged children, especially those with learning challenges in mathematics. With the MK part of the curriculum intervention, our approach was to help with metacognition. Metacognition is often an issue with students with learning difficulties in mathematics, and developing skills in the primary grades can make future success more likely (Rusyid & Juandi, 2023).

In Study 1, the researchers received recommendations from the teachers to reduce the MK portion, increase the CSK portion, and make the visits by the research assistant teaching the lesson with the teacher long enough (duration of weeks) for successful intervention, but not so long that future teachers would have trouble incorporating it into their already busy schedules. In Study 2 (see below), we incorporated this feedback and also significantly modified the curriculum to incorporate STEAM (science, technology, engineering, and mathematics with the arts) to investigate how students acquired concepts in a condensed curriculum intervention with STEAM. We predicted that a curriculum with STEAM would be even more effective because it was more hands-on, multi-sensory and creative (Perignat & Katz-Buonincontro, 2019).

Study 2

Participants

A total of 113 students, 87 in Grade 4 and 26 in grade 5, from five elementary schools in Vancouver BC, Canada, participated in Study 2, with 96 students meeting criteria for inclusion for analysis. There were three control and three treatment classes. The mean age was 113 months and 119 months for the treatment and control group, respectively.

Design

The overall design was the same as in Study 1, with some modifications noted below. Three new classes were assigned to the treatment group and three new classes to the control group. The same analyses were conducted as with the Study 1 sample. Pretests of measurement knowledge (MK) and climate science knowledge (CSK) were administered in January, and the posttests were conducted in April, 1-3 weeks after the curriculum ended. Tests such as Word Attack, Word-Letter Identification, Vocabulary, and ITBS Math were administered along with the pretests. Classes in the control group received the British Columbia (BC) science and mathematics curriculum as well as visits from a graduate research assistant to teach lessons in topics unrelated to the climate change intervention (e.g., general ecology lessons on food webs) from one to three times a week with their regular classroom teacher, with each session lasting 30 to 40 minutes.

The disciplines addressed in the treatment (curriculum intervention) classes were greatly expanded compared to those in Study 1, including (a) chemistry (e.g., atoms and molecules, elements and compounds, energy and matter, states and state changes of matter, scientific graph interpretation, chemical bonding, fossil fuel formation and burning, and coral reef bleaching); (b) mathematics and measurement (e.g., linear measurement, area, volume, rate, weight, and temperature); and (c) physics (e.g., thermodynamic energy of a system and scientific graph interpretation).

Instruction in treatment classes was given to classes of 25 to 30 students from January to May once a week in periods of 60 to 90 minutes based on the regular classroom teachers' schedules. By the time the posttests were administered, classes in the treatment group had received instruction for 9 to 12 sessions. Thus, the whole curriculum was covered in Study 2.

Compared to Study 1, measurement concepts were reduced and more science concepts were covered, including scientific graph interpretation, chemical bonding (e.g., ionic and covalent bonds, electrons, protons, neutrons, the Bohr model, and periodic table patterns), fossil fuel formation and burning, molecular structure and properties of the greenhouse gases and coral reef bleaching. These interventions were delivered by a research assistant in collaboration with classroom teachers.

Curriculum Intervention Instruction

The curriculum was divided into 10 units. The first three units focused on scale of measurement, and the remaining seven each focused on one scientific phenomenon. The curriculum did not overlap with the BC curriculum for Grade 4 and 5 students. In addition, the science content covered was more advanced than what is taught at the Grade 4 or 5 level. Study 2 had less mathematics than in Study 1, given teachers' feedback to spend more time on the higher-level scientific concepts.

Delivery of the curriculum was different than in Study 1. In addition to the hands-on activities and visual illustrations, art activities were integrated with science concepts to promote active learning for students of all backgrounds (STEAM; de Sousa & Pilecki, 2013). STEAM activities varied from performance activities with balloons to illustrate molecular structure models (e.g., carbon dioxide) to climate change mural drawings. For example, a skit activity was integrated in learning temperature and graphing. At the front of the classroom, two children held up pom-poms to indicate two points on the graph (time x1, temperature y1; time x2, temperature y2). Another two children orientated themselves around the dots, holding wooden dowels to represent the x (horizontal) and y (vertical) axes while two other children held up small white boards with "Temperature" written for the y axis and "Time" for the x axis. One child was the "writer," meaning that they wrote "Temperature" and "Time" on the whiteboards. The last child held up a ruler (given that drawing a graph by hand often requires a ruler to help plot the graph).

Testing of the Curriculum Intervention

Measurement Knowledge

The MK test was adapted from the one used in Study 1. It covered content including perimeter, area, and volume. The number of items for each subject area was reduced, shortening the test to 24 items. However, the test format remained the same, consisting of multiple-choice and short-answer questions. Three graduate research assistants marked the short-answer questions together and reached agreement. The internal reliability coefficient was 0.72 for the pretest and 0.87 for the posttest.

Climate Science Knowledge

The CSK test was adapted from the one used in Study 1. Consisting of 48 items, it covered more content, including states of matter, molecular structure, and global warming. However, the test format remained the same as the one used in Study 1, consisting of true or false questions as well as multiple-choice and short-answer questions. Three graduate research assistants marked the short-answer questions together and reached agreement. The internal reliability coefficient was 0.78 for the pretest and 0.91 for the posttest.

Reading and Mathematics Skills

The standardized tests used in Study 1 were used to determine students' reading skills. ITBS Math was also used again; however, a shorter version consisting of 22 items was used due to teachers' request to reduce the testing time. The reliability alpha of the shortened version was 0.76.

Data Analysis

The same statistical model approaches as in Study 1 were used (see Study 1 for details).

Results

The Dichotomous Approach

Table 3 shows descriptive statistics results on pre- and posttests for CSK and MK of the LD and typically achieving groups.

Climate Science Knowledge. A three-way ANOVA was performed to assess the effects of treatment, learning performance (LP: LD vs. typically achieving), and time (pre- vs. posttest) on CSK. The ANOVA detected significant main effects for treatment, $F(1, 109) = 31.33$, $p < 0.05$; LP, $F(1, 109) = 34.63$, $p < 0.05$; and time, $F(1, 109) = 292.08$, $p < 0.05$, for CSK. These findings suggest that the climate change curriculum instruction more effectively enhanced students' understanding of climate science than regular instruction. While typically achieving students generally performed better on the CSK than LD students, both groups' CSK scores improved over time. Furthermore, the two-way interactions between treatment and time, $F(1, 109) = 174.69$, $p < 0.05$, and between LP and time, $F(1, 109) =19.19$, $p < 0.05$, were significant. The results also indicated a significant three-way interaction effect between treatment, LP and time, $F(1, 109) = 13.83$, $p < 0.05$. Post hoc analysis showed that students' CSK scores increased significantly from pre- to posttest for typically achieving students in both the control group, $t(38) = -3.73$, $p < 0.05$, and the treatment group, $t(24) = -13.56$, $P < 0.05$. Finally, the results indicated that the posttest CSK scores for students with LD in the treatment group were significantly higher than in the pretest, $t(30) = 11.41$, $p < 0.05$.

Measurement Knowledge. The three-way ANOVA analysis identified significant main effects due to both LP, $F(1, 109) = 12.73$, $p < 0.05$, and time, $F(1, 109) = 253.00$, $p < 0.05$, on MK scores. Similar to Study 1, students with LD had lower MK scores than their typically achieving counterparts. Also, there was a significant improvement in students' MK scores from pre- to posttest. The results revealed a significant two-way interaction effect between LP

Table 3
Percent Correct for the CSK and MK Pre- and Posttests for Students With Learning Difficulties (LD) and Typically Achieving (Typical) Given Control and Treatment Groups in Study 2

	Climate Science Knowledge			Measurement Knowledge	
	N	*Mean*	*SD*	*Mean*	*SD*
Pretest					
Control, LD	18	13.7	6.37	28.2	13.3
Treatment, LD	31	13.6	5.66	29.8	10.9
Control, Typical	39	21.2	9.48	35.8	14.1
Treatment, Typical	25	19.5	8.85	30.7	10.6
Posttest					
Control, LD	18	16.3	8.1	44.4	14.5
Treatment, LD	31	31.4	10.8	46.1	13.3
Control, Typical	39	24.9	10.6	62.7	17.2
Treatment, Typical	25	50.3	14.3	53.8	15.7

and time on MK, $F(1, 109) = 11.19$, $p < 0.05$. Post hoc testing revealed that the post-MK scores of students in both the control and the treatment group improved. For students with LD in the control group, there was a significant difference in MK between the pre- and posttest, $t(17) = -5.19$, $p < 0.05$. A significant difference was also found in students with LD in the treatment group, $t(30) = -8.02$, $p < 0.05$. Similarly, students in the control group exhibited a significant difference in MK, $t(38) = -11.24$, $p < 0.05$. A significant difference was observed in MK for typically achieving students in the treatment group, $t(24) = -9.18$, $p < 0.05$.

The Continuous Approach

The estimated fixed effects in the models are shown in Table 4. The fixed effects in Model 1 explained 43.4% of the variance in CSK and 38.1% of variance in MK. The fixed effects in Model 2 explained 49.8% of the variance in CSK and 51.4% of the variance in MK.

Is instruction effective in improving children's climate science knowledge and measurement knowledge? The instruction was effective in CSK, as indicated by the significant interaction between time and group in Model 1 (Estimate = 20.85, $p < 0.001$) and Model 2 (Estimate = 20.53, $p < 0.001$). However, the instruction was not effective on MK, as indicated by the nonsignificant two-way interaction between time and group.

Do reading and mathematics skills influence gains from the instruction? Reading ability was not associated with the initial level of CSK or MK. In contrast, mathematical ability was significantly associated with the initial level of CSK and MK (both $p < 0.05$). Mathematical ability was associated with gain in MK ($p < 0.05$).

Discussion

In Study 2, the effect of the STEAM CSK curriculum was statistically significant. The children also expressed interest throughout the visits. They seemed to especially like doing a mural activity and hands-on skits related to the curriculum. For

Table 4

Fixed Effects in Linear Mixed-Effect Models Predicting Climate Science Knowledge (CSK) and Measurement Knowledge (MK) in Study 2

Model Parameters	CSK		MK	
	Est. (SE)	*t*	*Est. (SE)*	*t*
		Model 1		
Intercept	18.46 (1.49)	12.36***	32.93(1.99)	16.51***
Exp vs. Con	-1.87 (2.11)	-0.89	-2.81(2.82)	-1.00
Pre vs. Post	3.31 (1.25)	2.65**	22.77(1.87)	12.16***
Reading	0.08 (0.08)	1.11	0.10(0.10)	0.98
Exp*Post	20.85 (1.76)	11.83***	-3.30(2.65)	-1.25
Exp*Reading	-0.02 (0.10)	-0.20	-0.11(0.13)	-0.88
Post*Reading	0.00 (0.06)	-0.03	0.17(0.10)	1.78
Exp*Post*Reading	0.12 (0.08)	1.54	-0.15(0.12)	-1.20
		Model 2		
Intercept	18.44 (1.37)	13.45***	32.85 (1.72)	19.10***
Exp vs. Con	-1.90 (1.95)	-0.97	-2.28 (2.44)	-0.93
Pre vs. Post	3.21 (1.24)	2.60**	23.25 (1.78)	13.04***
Math	1.12 (0.33)	3.43***	1.47 (0.41)	3.59***
Exp*Post	20.53 (1.76)	11.70***	-3.51 (2.53)	-1.38
Exp*Math	-0.41 (0.48)	-0.85	-0.44 (0.61)	-0.72
Post*Math	0.23 (0.29)	0.80	0.84 (0.42)	1.99*
Exp*Post*Math	0.21 (0.44)	0.49	0.18 (0.63)	0.29

Note. Con = control group; Est = estimate; Exp = experimental group; Math = mathematics skills; Post = posttest; Pre = pretest; Reading = reading skills; *SE* = standard error; *t* = t-value.

example, in one class a group of Grade 4 boys decided on their own to find and memorize a periodic table song and sing it for their class. The children also enjoyed the STEAM approach. When students were asked what they enjoyed, one 9-year-old boy wrote "I enjoyed the mural … everything." A 9-year-old girl mentioned that she enjoyed "individual testing" and "learning about coral," and wrote that trees "breathe in carbon dioxide and breathe out oxygen" and that "global warming is happening too fast." Anecdotally, teachers appeared to experience more anxiety around the concepts than their students. Children may be more willing to learn difficult topics. Students reported enjoying what they were learning even if topics were difficult.

The effect of the shortened MK curriculum did not significantly differ from the mathematics instruction with the regular BC curriculum, which was unsurprising as the BC curriculum covered similar topics (https://curriculum.gov.bc.ca/curriculum/mathematics). We reduced the emphasis of MK instruction, given feedback from teachers in Study 1 to focus more on CSK.

General Discussion

Porter et al. (2012) showed that Grade 6 students acquired climate-change scientific concepts, but their study did not compare typically achieving students to students with LD. The present study not only showed improved performance of LD and typically achieving students in Grades 4 and 5 but also that even younger students can show an overall increase in the understanding of the basic science concepts underlying climate change. Furthermore, our research indicated that students with LD in treatment classes improved compared to control classes (Study 1 and 2), and the effect appeared strongest with a STEAM delivery (Study 2). Therefore, we recommend using a STEAM approach. For example, we noticed that the children in our study often loved drawing, plays, skits, singing, and other forms of creativity. Recent research suggests that the type of pedagogy, such as more creative Montessori vs. more traditional teaching, can impact creative performance and brain activity (Duval et al., 2023). The immense challenges posed by climate change will require highly creative problem solving.

We also suggest that future research examine more in-depth how learning strengths and deficits impact the ability to learn the science underlying climate change in primary grades. We found, for example, that high-level vocabulary could act as a barrier when learners were attempting to express their understanding during the assessment testing for MK and CSK.

Some caveats regarding the type of testing used in this research bear mentioning. Given the nature of the complex terminology, many students were better able to explain the concepts orally than on paper. In future studies, therefore, we suggest conducting structured interviews with students to assess their understanding. In the current study, we did not follow the students after the study to see their retention of the complex concepts; this would be an interesting topic for future research.

Finally, we suggest that primary school teachers receive more training to enable them more successfully teach the science behind climate change. In a study of 20 primary school teachers, Ratinen and colleagues (2013) found that these teachers were lacking the tools to help their students fully overcome misconceptions about climate change science. Furthermore, de Sousa et al. (2019) noted that primary school teachers lacked the systems thinking skills to explain the connection between soil science and climate change science.

Conclusion

Climate change is a threat to humans and our planet, and the sooner we take action the better (Lee et al., 2023; Steel et al., 2022). Accurate teaching of science concepts as early as possible helps prevent misunderstanding later in life (Stein & Raudenbush, 2013). Currently, however, climate change curriculum interventions typically do not start until middle school and beyond (see Monroe et al., 2017). To our understanding, our research is the first to examine such interventions for elementary school children while comparing students with learning difficulties with their typically achieving peers. As illustrated here, 9- to 11-year-old children can learn about scientific concepts underlying climate change, especially with interactive instruction. Students with learning difficulties tend to start at a lower baseline, but in our study, these students still learned concepts that are more commonly learned in high school and postsecondary education. The use of STEAM was more effective than just visuals for all students overall; students enjoy. learning difficult concepts more when there is an element of play and creativity. We recommend that future work that builds on this research also uses STEAM. STEAM can better support universal design for learning (UDL) in science, and UDL can help reduce barriers for all learners (Super et al., 2021).

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