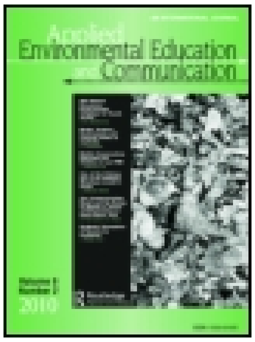

Applied Environmental Education & Communication

ISSN: 1533-015X (Print) 1533-0389 (Online) Journal homepage: https://www.tandfonline.com/loi/ueec20

New York City fourth graders who receive a climate change curriculum with hydroponic gardening have higher science achievement scores

Kate G. Burt, Marissa Burgermaster, Dina D'Alessandro, Rachel Paul & Marina Stopler

APPLIED ENVIRONMENTAL EDUCATION & COMMUNICATION
https://doi.org/10.1080/1533015X.2019.1611504

New York City fourth graders who receive a climate change curriculum with hydroponic gardening have higher science achievement scores

Kate G. Burt[a], Marissa Burgermaster[b], Dina D'Alessandro[a], Rachel Paul[c], and Marina Stopler[a]

[a]Lehman College, City University of New York, New York City, NY, USA; [b]University of Texas at Austin, Austin, TX, USA; [c]Teachers College, Columbia University, New York City, NY, USA

ABSTRACT
We compared 2014–15 New York State Science Assessment scores of fourth grade students who received the New York Sun Works (NYSW) Program (n = 638) with two comparison groups: students who received NYSW the following year (n = 993) and students attending matched schools (n = 1490). We first applied a multi-level regression model to compare scores between NYSW recipients and the first comparison group, which revealed non-significant but higher scores among NYSW recipients. We then compared the achievement scores of the NYSW recipients to both comparison groups using Welsch two sample *t*-tests. On average, NYSW recipients scored significantly higher than both the comparison groups ($p < 0.001$). Results suggest that further testing should explore the impact of climate change education on science achievement.

Introduction

Science achievement in the United States (US) lags behind other countries. Currently, the US is ranked 38th out of 71 industrial countries in mathematics and science, based on the Organization for Economic Co-Operation and Development's Program for International Student Assessment's (PISA) knowledge and skills tests (Desilver, 2017). A startling 24% of fourth graders, 32% of eighth graders, and 40% of twelfth graders' scores were "below basic" on the US Department of Education's National Assessment of Educational Progress and fewer than 33% of students achieved a score of "proficient" (Desilver, 2017).

That American students lack a strong science background is of particular concern because the US contributes more to climate change than any other country (Matthews et al., 2014). Climate change is an urgent global issue warranting international attention (Goal 13, 2016). Limited natural

CONTACT Kate G. Burt katherine.burt@lehman.cuny.edu Lehman College, City University of New York, New York City, NY, USA.

resources and changes to the environment, such as the increase in the average global temperature and increase in greenhouse gas emissions, have been shown to contribute to many of our pervasive health issues including respiratory illnesses, cancer, and heart disease (Portier et al., 2010). Advances in technology are essential to mitigate the deleterious effect of climate change on human health and hydroponics (growing food without soil in nutrient-rich water) is a potential solution (Klein et al., 2006). Utilizing new tools, like hydroponics, to address current environmental concerns will require high quality environmental education that raises awareness, improves critical thinking skills, and builds the capacity of children to become leaders in sustainable development (Goal 13, 2016).

Evidence suggests that climate change education (CCE) improves climate science knowledge and students' capacity to fight climate change (Kabir, Rahman, Smith, Lusha, & Milton, 2015; Karpudewan, Roth, & Abdullah, 2015; Lutz, Muttarak, & Striessnig, 2014; Varma & Linn, 2012). Children who learn about the state of our natural environment are given an early opportunity to understand their role in supporting sustainability on both a local and global level and, in doing so, they garner a deeper understanding about prosocial behaviors and community interdependence (Wray-Lake & Syvertsen, 2011). Pro-environmental behavior, as well as environmental efficacy and social activism, is also improved among children when their science knowledge related to climate change is expanded and they use problem-based strategies to cope with climate change's deleterious effect (e.g. seeking information about actions they may take to lessen the negative impacts) (Lester, Ma, Lee, & Lambert, 2006; Ojala, 2012). Integrating climate focused lessons into science education has also been shown to promote critical thinking skills and enhance students' views of themselves as agents of change (Church & Skelton, 2010; Kontra et al, 2015). Results of these studies indicate that when students learn about climate change, they may be more likely to take action to reduce their environmental impact.

Certain educational approaches of environmental education have been shown to improve environmental literacy and science achievement, such as problem-based inquiry, experiential learning, and technology applications (Grabau & Ma, 2017; Marshall, Smart, & Alston, 2017). For example, gardening in schools provides evidence for a myriad of benefits to students, including improved science knowledge (Williams & Dixon, 2013). Learning about sustainability through food has been shown to improve attitudes toward science, which may lead to better engagement and improved learning (Lebo & Eames, 2015). As CCE is one type of environmental education, it may be true that applying these approaches to CCE curricula not only improves students' attitudes towards climate change and pro-environmental behaviors, but also science achievement.

However, the impact of CCE on science achievement has been understudied. CCE interventions often assess knowledge gains in ways that are not comparable to gains from a traditional science curricula or to science knowledge in general. A recent review of 49 CCE interventions reported that knowledge gains were measured through one of the following methods: unvalidated pre- and post-test assessments developed by the researchers for their specific intervention, measures developed and validated by independent research team(s), tools validated by other researchers, or by another method (e.g. survey or interview) (Monroe, Plate, Oxarart, Bowers, & Chaves, 2017). To date, there have been no studies to assess the impact of CCE on students' science achievement scores on standardized tests (Lederman & Abell, 2014; Stevenson, Brody, Dillon, & Wals, 2013). Given that current educational system measures academic gains using standardized tests, in order for CCE to become mandated on a large scale, it is critical to demonstrate the potential impact of CCE on students' standardized achievements scores.

In order to have an impact on science achievement, CCE curricula need to be aligned with mandated educational standards. One CCE program that does is the New York Sun Works (NYSW) Greenhouse Project Initiative, which couples a kindergarten through twelfth grade climate and sustainability curriculum with hydroponic food labs in schools in the New York City (NYC). The inquiry-based curriculum focuses on real-world climate challenges through project-based learning in modules while the labs are used to conduct experiments as small scale farms. The NYSW program applies best practices in environmental education, including experiential learning, problem-based inquiry, and technology applications to topics specifically addressing climate science. It also meets the New York State Department of Education mandated science standards. The aim of this quasi-experimental exploratory study was to compare New York State Science Achievement test scores of fourth grade elementary school students who received the NYSW program to those who did not receive the NYSW program in 2014–15.

Methods

Program description

Since 2012, the NYSW Greenhouse Project Initiative, which builds customized classroom-based hydroponic labs and provides a kindergarten through twelfth grade curriculum, has addressed environmental issues including climate change and sustainability in schools in NYC. The curriculum meets New York State's Science Scope and Sequence requirements, which are mandated standards for science education. Features of the NYSW program include hydroponic and aquaponic systems, worm-composting, rainwater catchment systems used for cooling and irrigation, and pest management and are either integrated into a full-scale greenhouse or into an existing converted classroom, based on the school's preference. All students at NYSW schools receive the same curriculum, regardless of the systems on site.

The NYSW program aims to educate students about climate change and urban sustainability in order to identify and explain real-world climate problems affecting communities, such as biodiversity and pollution, through hydroponic gardening and a project-based curriculum. The ultimate goal of the program is to increase students' engagement with and achievement in science. In schools that adopt the NYSW program, a classroom is converted into a science lab, with hydroponic and/or aquaponic technology used as a tool to enhance the NYSW STEM (science, technology, engineering, and mathematics) focused curriculum. The curriculum explores biology, chemistry, physics, earth sciences, and the environment through hands-on activities related to urban farming ("Programming", 2017).

NYSW provides an intensive 36-h training to teachers that can be counted toward mandated professional development credit hours to enhance teachers' knowledge, skills, and effectiveness in teaching the curriculum. The elementary curriculum (i.e. kindergarten through fifth grade) is comprised of 80 lessons delivered twice weekly throughout the school year. Hydroponic gardening is incorporated into lessons at all educational levels so that students plant, nurture, and grow food in the classroom-based closed systems. Hydroponics is also the basis for the project-based activities (long- and short-term, individual and group projects); projects are a focus of the curriculum at all levels in order to enhance student engagement with the course material and develop real-world experiments.

Study sites and participants

We obtained 2014–15 achievement scores on the New York State science assessment for fourth grade students (n = 638) in six elementary schools implementing the NYSW program from three NYC boroughs (Manhattan, Brooklyn, and Queens). Fourth grade was the only group included in this study because it is the only year of elementary school during which a standardized science test is administered.

The NYSW comparison group consisted of the achievement scores of students (n = 993) at eight elementary schools that were scheduled (i.e. not randomly selected) to receive the NYSW Program the following year. The state assessment measures content knowledge in a way that is similar to the National Assessment of Educational Progress and the international assessment Trends in International Mathematics and Science Study (Bohrstedt & Stancavage, 2016).

We also identified "peer" schools from the NYC Department of Education's (NYC DOE) School Quality Guides. Peer schools are identified by NYC DOE based on a multi-level matching method that focuses on demographic characteristics at the school and student level, including economic need (student housing status, percent of children eligible for free and reduced price lunch in a school), disability status, English Language Learner category, as well as previous test scores. This methodology is outlined at NYC DOE website (New York City Department of Education, 2017). By using the NYC DOE peer schools we could account for similarities at the school level, reducing selection bias and Type II error; therefore, we randomly selected two peer schools for each school implementing NYSW (14 schools) in order to reduce sampling variability (Austin, 2010). By using officially designated schools matched on demographic characteristics as comparisons, we reduced the potential for selection bias in our study sample. We obtained 2014–15 New York State science achievement scores for fourth grade students ($n = 1490$) in these schools. This study was approved by the Lehman College Institutional Review Board (file number 2016-0276).

Design and analytic method

In our quasi-experimental design, we first applied a multi-level regression model (i.e. hierarchical linear model) fit by maximum likelihood with school as random effects to account for clustering at the school level to compare students in NYSW schools who received the program ($n = 6$) to students in NYSW comparison schools who had not yet received the program ($n = 8$).

$$\text{Science Scale Score}_{ij} = \beta_{0j} + \beta_1(\text{NYSW}_{ij}) \; + r_{ij} \tag{L1}$$

$$\beta_{0j} = \gamma_{00} + \gamma_{01}\left(\text{School}_j\right) \; + u_{0j} \tag{L2}$$

Due to small level 2 sample sizes (six and eight, respectively) we expected the model to be underpowered, as literature on multi-level modeling indicates that level 2 n's of 30 or 50 are necessary (e.g. Raudenbush & Bryk, 2002; Snijders & Bosker, 2012). Therefore, we then compared students' science test scores in schools implementing NYSW to two different groups: (a) students in NYSW comparison schools and (b) students in NYC DOE peer schools using Welch two-sample *t*-tests, which accounts for uneven sample size. Analyses were conducted using R version 3.2.3 ("R Core Team", 2014).

Table 1. Multilevel regression model results comparing science assessment scores of students who received the New York Sun Works curriculum to students at New York City Department of Education peer schools who did not receive the curriculum.

	NYS scaled science scores			
Predictor	Estimates	*SE*		Df
(Intercept)**	76.9	2.5		979
NYSW*	8.1	3.7		12
Random effects				
	Intercept		Residual	
Standard deviation	6.8		12.3	
Observations	993			
Groups	14			

*$p < 0.05$.
**$p < 0.001$.

Results

The results of the multilevel regression model revealed that, on average, students in schools that received the NYSW curriculum had non-significantly higher achievement score by 8.1 ± 3.8 points compared to students in schools that did not ($b = 8.14$, $SE = 3.77$, $p = 0.052$) (Table 1).

Students who received the NYSW curriculum (n = 638) during the 2014–15 school year had a mean scaled science score of 85.1, students in the NYSW delayed control comparison group (n = 993) had a mean scaled science score of 75.91, and students in the DOE peer schools (n = 1490) had a mean scaled science score of 76.1 (Table 2). The Welsch two sample *t*-tests indicated students who received the NYSW curriculum scored significantly higher on the fourth grade science achievement test than students in the NYSW comparison group ($t = -10.93$, $p < 0.001$) and at NYC DOE peer schools ($t = -11.73$, $p < 0.001$).

Discussion

The multilevel model revealed higher science achievement scores among students who received NYSW that approached significance, despite being underpowered. In our second analysis comparing mean scores of NYSW students to students in comparison schools and peer schools, students who received the NYSW program scored significantly higher on the fourth grade New York State test compared to students in both the groups.

Though a quasi-experimental study design does not support any causal claims about the effect of the NYSW curriculum on science achievement, it is possible that the content of the NYSW program contributed to higher test scores. NYSW program content could contribute to science achievement because it make climates change and sustainability modules personally relevant to students and engages them by applying the content to real world scenarios. The fact that climate change is a topic that raises some social controversy may be an advantage, as it provides an opportunity for

Table 2. School-level characteristics of the New York Sun Works Program schools, schools scheduled to receive the New York Sun Works, and DOE Peer Matched schools, mean (SD).

Variables	2014–2015		
	NYSW	Scheduled to receive NYSW	DOE peer matched schools
Sample sizes	n = 638 6 schools	n = 993 8 schools	n = 1490 14 schools
School-level demographics			
% Eligible for free and reduced price lunch[a]	58.7 (41.1)	69.0 (32.3)	66.9 (31.4)
Race/ethnicity			
% Black	16.6 (20.8)	49.0 (33.0)	29.1 (31.6)
% Hispanic	45.6 (37.5)	29.8 (18.6)	35.4 (27.8)
% English language learners (ELL)	11.6 (14.6)	7.2 (6.1)	8.4 (7.1)
Academic achievement scores			
Mean scaled science score[b]	85.1 (13.3)	75.9 (15.1)	76.1 (17.4)

[a]Proxy measure for economic need index.

[b]Difference is significant ($p < 0.001$).

students to critically analyze contradicting scientific evidence, facilitates student engagement, and improves students' attitudes toward science which ultimately improve achievement (Cheung, Slavin, Kim, & Lake, 2017; Corso, Bundicks, Quaglia, & Haywood, 2013; Lebo & Eames, 2015; Walsh & Tsurusaki, 2014; Warburton, 2003).

Moreover, climate-related content may be particularly relevant to higher achievement because it is a topic that students are likely exposed to in out-of-school settings. Students may read or hear about climate change on social media, in the news media, from the President and other prominent political or social leaders, or from their parents and families. They may also encounter climate-related messaging in their daily lives (e.g. using recycling bins or banning plastic bags or straws). Therefore, CCE concepts may be reinforced in important ways that other science topics are not and students may feel that climate-related content is personally relevant. Personal relevance of material is a critical factor to student enjoyment and interest, which precipitates greater motivation to expand one's knowledge and understanding (Ainley & Ainley, 2011). Students who are engaged demonstrate higher levels of motivation and grit or persistence to attain greater academic achievement across race, gender, and socioeconomic strata (Fredricks, Blumenfeld, & Paris, 2004; Wang, Willett, & Eccles, 2011).

Aspects of the NYSW program design may also contribute to higher test scores. The NYSW program operationalizes newer, evidence-based pedagogical approaches to education (e.g. active, experiential, and inquiry-based learning through problem solving and critical thinking) and combines them with innovative practical applications (e.g. technology, hydroponics) (Table 3). These approaches and applications have been linked to improved science achievement, knowledge retention, conceptual development, and attitudes toward science (Carver & Wasserman, 2012; Grabau & Ma, 2017;

Table 3. Operationalization of evidence-based components within the NYSW program.

Evidenced-based educational component	NYSW program application
Pedagogical approaches	
Active learning	Students are expected to create projects that explore real-world problems
Experiential learning	Student led experiments related to hydroponics, aquaponics, composting, rain catchment, and pest management
Inquiry-based learning	In each lesson students explore the answer to a focusing question (constructivism)
Practical applications	
Technology applications	Computer based simulations, programing, and activities aimed to engage students with the human impact on climate change
Hydroponics	Hands-on hydroponic and aquaponic science labs using Nutrient Film Technique and fish farming among other components

Merritt, Lee, Rillero, & Kinach, 2017; Minner, Levy, & Century, 2010; Monroe, Plate, Oxarart, Bowers, & Chaves, 2017; Williams & Dixon, 2013).

In order to operationalize novel science content and inquiry-based education effectively, teachers must be comfortable facilitating hands-on activities and connecting concepts, have expertise maximizing classroom use and management, and be effective communicators and context experts to engage student interest (Shamsudin, Abdullah, & Yaamat, 2013). Underprepared, underqualified, or inadequately trained teachers tend to rely on direct instruction and traditional teaching methods, which negatively impacts student learning ("The world needs almost 69 million new teachers to reach the 2030 education goals", 2016). As such, without qualified and prepared teachers, the aforementioned experiential, inquiry-based educational approaches, and applications of technology are unlikely to be used effectively or used at all. However, teachers who deliver the NYSW curriculum undergo intensive training, which improves expertise and enables them to deliver high quality instruction and establish meaningful context for student work thereby improving student engagement in the curriculum (Corso et al., 2013).

In addition to a call to address teacher shortages and training, there have been calls for a global improvement of education on climate science, as CCE is not a standard educational practice despite the evidence-based benefits (United Nations, 2015). The United Nations Educational, Scientific and Cultural Organization (UNESCO) has set a goal through the Framework Convention on Climate Change and Education for Sustainable Development to establish a global education system that supports learning methodologies for critical thinking and problem-solving with regard to climate change using a cross-curricular, multidisciplinary approach (The One United Nations Climate Change Learning Partnership, 2013).

However, the current political and social milieu that emphasizes traditional science education and de-emphasizes CCE remains a barrier to widespread adoption of CCE. In 2015, only 8% of students worldwide met "proficient" PISA science achievement standards and about 20% scored below baseline levels, which indicates that performance levels on traditional science topics that have largely remained unchanged since 2006 ("PISA 2015: Results in Focus", 2018). Moreover, disparate public discourse about climate science highlights great divide about the relevance and importance of CCE (Chang, 2015). In combination, inadequate student preparedness in basic science and contentious public debate on climate change remain barriers to adopting CCE on a global scale.

Given the political volatility around CCE, our results may highlight pathways to include more climate science in K-12 schools, as desirability of higher test scores may take precedent over political opposition. In assessment-based educational systems, like in the US (and many educational systems worldwide), one of the most compelling ways to motivate policymakers to integrate CCE into curricula would be to demonstrate its effectiveness to improve general science achievement (Burt, Koch, & Contento, 2017). Doing so using widely accepted or validated measures (e.g. national or international standardized tests) could not only demonstrate the academic impact for students but would also enable researchers to compare the outcomes of various curricula. To date, research in this area has been lacking (Lederman & Abell, 2014; Stevenson, Brody, Dillon, & Wals, 2013), warranting the current study which indicates that students who receive CCE score higher on a standardized science assessment than those who do not. While more research is needed to investigate the causal relationship between CCE, science achievement, and related outcomes, the results of this study are promising as they may be used to create a new opportunity for policy that establishes CCE as a strategy to improve science achievement overall.

Strengths

This is one of the first studies to compare science achievement scores among students in schools that did and did not teach a sustainability and environmental education curriculum (Lederman & Abell, 2014; Stevenson, Brody, Dillon, & Wals, 2013).

Limitations

In this study, schools were not randomized to receive the curriculum; they opted to include NYSW, suggesting that they already value science or climate change in some way that might make them different from other schools. While the multilevel regression model would have accounted for this, we aimed to reduce clustering bias by conducting our second analysis with two different groups. By using the comparison group (e.g. delayed controls) comprised of schools with teachers opting into NYSW for the following school year, we accounted for teacher interest in science or a climate change curriculum. By using peer schools, an evaluation technique developed by the NYC DOE to account for clustering, we were also able to reduce clustering bias, as peer schools are determined to be comparable. Therefore, we cannot assume the curriculum alone explains why students in these schools had better scores, though comparing NYSW schools to the comparison group and to peer schools with similar demographic characteristics improves the validity of these results. Cluster-randomized control trials will better determine the effect of this type of curriculum on science achievement. Finally, we were unable to include a measure of fidelity of NYSW program implementation and we do not know additional details about any of the comparison or peer schools' teaching practices; both of these factors may have influenced test scores.

Conclusion and implications

Well-designed and rigorously implemented CCE may serve to address two important issues: improving science achievement among students and preparing those students to combat climate change as future leaders. Given the potential benefit of the NYSW program revealed in this study, it should be further tested across multiple years of intervention and in a comparative effectiveness trial and potentially considered for adoption in more schools that adhere to the US Common Score Science standards. Future research should use validated measures (e.g. standardized tests) in order to determine the potential impact of climate change education in general and to compare pedagogically distinct curricula to each other. Finally, while this study only explore science achievement scores, future research should evaluate the impact of CCE (including the NYSW program) on students' problem solving skills, and attitudinal and behavioral changes throughout elementary and secondary school.

ORCID

Kate G. Burt http://orcid.org/0000-0002-6115-6450
Marissa Burgermaster http://orcid.org/0000-0002-4891-3314

References

Ainley, M., & Ainley, P. (2011). Student engagement with science in early adolescence: The contribution of enjoyment to students' continuing interest in learning about science. *Contemporary Educational Psychology*, *36*(1), 4–12. doi:10.1016/j.cedpsych.2010.08.001

Austin, P. C. (2010). Statistical criteria for selecting the optimal number of untreated subjects matched to each treated subject when using many-to-one matching on the propensity score. *American Journal of Epidemiology*, *172*(9), 1092–1097. doi:10.1093/aje/kwq224

Bohrstedt, G., & Stancavage, F. (2016). TIMSS, PISA, and NAEP: What to know before digging into the results. Retrieved from http://educationpolicy.air.org/blog/timss-pisa-and-naep-what-know-digging-results

Burt, K. G., Koch, P., & Contento, I. (2017). Implementing and sustaining school gardens by integrating the curriculum. *Health Behavior and Policy Review*, *4*(5), 427–435. doi: 10.14485/HBPR.4.5.2

Carver, J., & Wasserman, B. (2012). Hands-on hydroponics: A long-term inquiry lesson on sustainability and plant biology. *The Science Teacher*, *79*(4), 44–48.

Chang, C. (2015). Teaching climate change – A fad or a necessity? *International Research in Geographical and Environmental Education*, *24*(3), 181–183. doi:10.1080/10382046.2015.1043763

Cheung, A., Slavin, R. E., Kim, E., & Lake, C. (2017). Effective secondary science programs: A best-evidence synthesis. *Journal of Research in Science Teaching*, *54*(1), 58–81. doi: 10.1002/tea.21338

Church, W., & Skelton, L. (2010). Sustainability education in K-12 classrooms. *Journal of Sustainability Education*, *1*(0), 1–13.

Corso, M. J., Bundicks, M. J., Quaglia, R. J., & Haywood, D. E. (2013). Where student, teacher, and content meet: Student engagement in the secondary school classroom. *American Secondary Education*, *41*(3), 50–61.

Desilver, D. (2017). US students' academic achievement still lags that of their peers in many other countries. *FacTank: News in the Numbers*. Retrieved March 24, 2017, from http://www.pewresearch.org/fact-tank/2017/02/15/u-s-students-internationally-math-science/

Fredricks, J. A., Blumenfeld, J. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*(1), 59–109. doi: 10.3102/00346543074001059

Goal 13: Take urgent action to combat climate change and its impacts. (2016). Sustainable Development Goals: 17 Goals to Change Our World. United Nations. Retrieved from http://www.un.org/sustainabledevelopment/climate-change-2/

Grabau, L. J., & Ma, X. (2017). Science engagement and science achievement in the context of science instruction: A multi-level analysis of US students and schools. *International Journal of Science Education*, *39*(8), 1045–1068. doi:10.1080/09500693.2017.1313468

Kabir, M. I., Rahman, M. B., Smith, W., Lusha, M. A. F., & Milton, A. H. (2015). Child-centered approach to climate change and health adaptation through schools in Bangladesh: A cluster randomized intervention trial. *PLoS ONE*, *10*(8), 1–17.

Karpudewan, M., Roth, W., & Abdullah, M. (2015). Enhancing primary school students knowledge about global warming and environmental attitude using climate change activities. *International Journal of Science Education*, *37*(1), 31–54. doi:10.1080/09500693.2014.958600

Klein, R. J., Alam, M., Burton, I., Dougherty, W. W., Ebi, K. L., Fernandes, M., … Swartz, C. (2006). *Application of environmentally sound technologies for adaptation to climate change*. United Nations Framework Convention on Climate Change. Retrieved from http://unfccc.int/resource/docs/publications/tech_for_adaptation_06.pdf

Kontra, C., Lyons, D. J., Fischer, S. M., & Beilock, S. L. (2015). Physical experience enhances science learning. *Psychological Science*, *26*(6), 737–749. doi:10.1177/0956797615569355

Lebo, N., & Eames, C. (2015). Cultivating attitudes and trellising learning: A permaculture approach to science and sustainability education. *Australian Journal of Environmental Education*, *31*(1), 46–59. doi:10.1017/aee.2015.23

Lederman, N., & Abell, S. (Eds.). (2014). *Handbook of research on science education, Volume 2*. New York: Routledge.

Lester, B. T., Ma, L., Lee, O., & Lambert, J. (2006). Social activism in elementary science education: A science, technology, and society approach to teach global warming. *International Journal of Science Education*, *28*(4), 315–339. doi:10.1080/09500690500240100

Lutz, W., Muttarak, R., & Striessnig, E. (2014). Universal education is key to enhanced climate adaptation. *Science*, *346* (6213), 1061–1062. doi:10.1126/science.1257975

Matthews, H. D., Graham, T. L., Keverian, S., Lamontagne, C., Seto, D., & Smith, T. J. (2014). National contributions to observed global warming. *Environmental Research Letters*, *9*(1), 014010. doi:10.1088/1748-9326/9/1/014010

Marshall, J. C., Smart, J. B., & Alston, D. M. (2017). Inquiry-based instruction: A possible solution to improving student learning of both science concepts and scientific practices. *International Journal of Science and Mathematics Education*, *15*(5), 777–796. doi:10.1007/s10763-016-9718-x

Merritt, J., Lee, M., Rillero, P., & Kinach, B. M. (2017). Problem-based learning in K–8 mathematics and science education: A literature review. *Interdisciplinary Journal of Problem-Based Learning*, *11*(2). https://docs.lib.purdue.edu/ijpbl/vol11/iss2/3/

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction – What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496. doi:10.1002/tea.20347

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2017). Identifying effective climate change education strategies: A systematic review of the research. Journal of *Environmental Education Research*, 1. doi:10.1080/13504622.2017.1360842

New York City Department of Education. (2017). School quality reports: Using comparison schools to better understand a school's performance. New York, NY. Retrieved from https://infohub.nyced.org/docs/default-source/default-document-library/schoolqualityreports_comparisongroupdescription_20171204fc489b8b347e46bf801e38ceed4b3069.pdf?sfvrsn=e747dd75_2

North American Association for Environmental Education (NAAEE). (2010). Excellence in *environmental education:* Guidelines for *l*earning (K-12). NAEE, Washington, DC. Retrieved from http://resources.spaces3.com/89c197bf-e630-42b0-ad9a-91f0bc55c72d.pdf

Ojala, M. (2012). How do children cope with global climate change? Coping strategies, engagement, and well-being. *Journal of Environmental Psychology*, *32*(3), 225–233. doi:10.1016/j.jenvp.2012.02.004

Organisation for Economic Co-Operation and Development. (2018). PISA 2015: Results in *f*ocus. Retrieved from https://www.oecd.org/pisa/pisa-2015-results-in-focus.pdf

Portier, C. J., Thigpen Tart, K., Carter, S. R., Dilworth, C. H., Grambsch, A. E., Gohlke, J., … Whung, P. Y. (2010). *A human health perspective on climate change: A report outlining the research needs on the human health effects of climate change*. Research Triangle Park, NC: Environmental Health Perspectives/National Institute of Environmental Health Sciences. Retrieved from www.niehs.nih.gov/climatereport

Programming. (2017). Retrieved from http://nysunworks.org/education/programming/

R Core Team. (2014). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org/

Raudenbush, S. W., & Bryk, A. S. (2002). *Hierarchical liner models: Applications and data analysis methods* (2nd ed.). London, UK: Sage Publications.

Stevenson, R., Brody, M., Dillon, J., & Wals, A. (Eds.). (2013). *International handbook of research on environmental education*. New York: Routledge.

School Quality Reports: Using "Comparison Group" Results To Better Understand a School's Performance. (2015). Retrieved from http://schools.nyc.gov/NR/rdonlyres/EC61C6E7-C71C-4B0B-A0B3-37E19354550E/0/SchoolQualityReports_ComparisonGroupDescription_20151209.pdf

Shamsudin, N. M., Abdullah, N., & Yaamat, N. (2013). Strategies of teaching science using an inquiry based science education (IBSE) by novice chemistry teachers. *Procedia Social and Behavioral Sciences*, *90*, 583–592. doi:10.1016/j.sbspro.2013.07.129

Snijders, T. A., & Bosker, R. J. (2012). *Multilevel analysis: An introduction to basic and advanced multilevel modeling* (2nd ed.). London, UK: Sage Publishers.

The One United Nations Climate Change Learning Partnership. (2013). Resource guide for advanced learning on integrating climate change in education at primary and secondary level. New York, NY. Retrieved from http://www.uncclearn.org/sites/default/files/inventory/resource_guide_on_integrating_cc_in_education_primary_and_secondary_level.pdf

The world needs almost 69 million new teachers to reach the 2030 education goals (UIS Fact Sheet No. 39). (2016). Retrieved September 26, 2018, from UNESCO Institute for Statistics website: http://uis.unesco.org/sites/default/files/documents/fs39-the-world-needs-almost-69-million-new-teachers-to-reach-the-2030-education-goals-2016-en.pdf

United Nations. (2015). *Transforming our world: The 2030 Agenda for Sustainable Development*. Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

Varma, K., & Linn, M. C. (2012). Using interactive technology to support students' understanding of the greenhouse gas effect and global warming. *Journal of Science Education and Technology*, *21*(4), 453–464. doi:10.1007/s10956-011-9337-9

Walsh, E. M., & Tsurusaki, B. K. (2014). Social controversy belongs in the climate science classroom. *Nature Climate Change*, *4*(4), 259–263. doi:10.1038/nclimate2143

Wang, M., Willett, J. B., & Eccles, J. S. (2011). The assessment of school engagement: Examining dimensionality and measurement invariance by gender and race/ethnicity. *Journal of School Psychology*, *49*(4), 465–480. doi:10.1016/j.jsp.2011.04.001

Warburton, K. (2003). Deep learning and education for sustainability. *International Journal of Sustainability in Higher Education*, *4*(1), 44–56. doi:10.1108/14676370310455332

Williams, D. R., & Dixon, P. S. (2013). Impact of garden-based learning on academic outcomes in schools: Synthesis of research between 1990 and 2010. *Review of Educational Research*, *83*(2), 211–235. doi:10.3102/0034654313475824

Wray-Lake, L., & Syvertsen, A. K. (2011). The developmental roots of social responsibility in childhood and adolescence. *New Directions for Child and Adolescent Development*, *Winter 2011*(134), 11–25. doi:10.1002/cd.308