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The Effects of School Gardens on Children's Science Knowledge: A randomized controlled trial of low-income elementary schools

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This randomized controlled trial or 'true experiment' examines the effects of a school garden intervention on the science knowledge of elementary school children. Schools were randomly assigned to a group that received the garden intervention ($n = 25$) or to a waitlist control group that received the garden intervention at the end of the study ($n = 24$). The garden intervention consisted of both raised-bed garden kits and a series of 19 lessons. Schools, located in the US states of Arkansas, Iowa, Washington, and New York, were all low-income as defined by having

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50% or more children qualifying for the federal school lunch program. Participants were students in second, fourth, and fifth grade (ages 6–12) at baseline ($n = 3{,}061$). Science knowledge was measured using a 7-item questionnaire focused on nutritional science and plant science. The survey was administered at baseline (Fall 2011) and at three time points during the intervention (Spring 2012, Fall 2012, and Spring 2013). Garden intervention fidelity (GIF) captured the robustness or fidelity of the intervention delivered in each classroom based on both lessons delivered and garden activities. Analyses were conducted using general linear mixed models. Survey data indicated that among children in the garden intervention, science knowledge increased from baseline to follow-up more than among control group children. However, science knowledge scores were uniformly poor and gains were very modest. GIF, which takes into account the robustness of the intervention, revealed a dose–response relation with science knowledge: more robust or substantial intervention implementations corresponded to stronger treatment effects.

Keywords: *Science knowledge; Schools; Gardens; School gardens; Children*

Introduction

> Where schools are equipped with gardens … opportunities exist for reproducing situations of life, and for acquiring and applying information … Gardening need not be taught either for the sake of preparing future gardeners, or as an agreeable way of passing time … [gardens] are a means for making a study of the facts of growth, the chemistry of soil, the role of light, air, moisture … (Dewey (1916, p. 235)

School gardens are far from new as a pedagogical tool. School gardens (along with outdoor and experiential learning more generally) have a long history in a variety of educational philosophies including those of Rousseau, Montessori, and Dewey (see Desmond, Grieshop, & Subramaniam, 2002; Subramaniam, 2002; Trelstad, 1997). John Amos Comenius (1592–1670), the father of modern education, advocated that 'A garden should be connected with every school, where children can at times gaze upon trees, flowers, and herbs, and be taught to enjoy them' (Weed & Emerson, 1909, p. 42). Although school gardens were promoted in the late 1800s and early 1900s—both in Britain and in the USA—with aims to address issues of city beautification, public health, and the development of good citizens, with relatively little focus on educational outcomes, prior to that era the initial school garden movement was sparked by the Nature-Study Movement, with the central aim to make learning interactive through the use of nature (Hayden-Smith, 2014; Trelstad, 1997). Dewey endorsed gardening as part of his 'object teaching' pedagogy employing hands-on learning rather than rote memorization (Dewey, 1916; Trelstad, 1997). School gardens are one way to bring learning outside the walls of the school and to employ engagement with nature as an experiential learning strategy (Desmond et al., 2002; Moore, 1995; Subramaniam, 2002) (see Figure 1; The Brookline Connection, photo 1916). The potential for garden-based learning has, more recently, been described as 'encompass[ing] programs, activities and projects in which the garden is the foundation for integrated learning, in and across disciplines, through active, engaging, real-world experiences' (Desmond et al., 2002, p. 7). And yet, aside from a brief reappearance as part of World War II victory

Figure 1. Students from Brookline elementary, Brookline Massachusetts work the school garden, 1916 (Source: The Brookline connection)

garden efforts (Hayden-Smith, 2014; Ossian, 2011), the current resurgence of school gardens follows a long period of relative dormancy since World War I (Trelstad, 1997).

In the twenty-first century, school gardens have gained prominence worldwide (Food and Agriculture Organization [FAO], 2010). Today, examples of the school garden movement are seen globally in: the thousands of schools that have joined 'The Edible Schoolyard Project' (2015) that has grown out of chef Alice Water's 'edible schoolyard' in Berkeley, CA; US first lady Michelle Obama's White House garden (Obama, 2012); the Royal Horticulture Society's 'Campaign for School Gardens' (Royal Horticulture Society, 2014); the EduPlant program in South Africa (FAO, 2010); the GATE program, in Belize, organized by the non-government organization Plenty Belize (FAO, 2010); and the Stephanie Alexander Kitchen Garden Foundation in Australia (Stephanie Alexander Kitchen Garden Foundation, 2015); to name a few. In addition, there are countless local and regional initiatives that have increased the visibility of gardening in general—and school gardens in particular. The current resurgence of school gardening is motivated by a variety of converging aims including to advance environmental sustainability (FAO, 2010; Moore, 1995); to enhance environmental education (Cutter-Mackenzie, 2009; Skelly & Bradley, 2007); to promote public health (Christian, Evans, Conner, Ransley, & Cade, 2012; Ozer, 2007; Story, Nanney, & Schwartz, 2009; Twiss et al., 2003) through diet (Christian et al., 2012; Morgan et al., 2010; Ratcliffe, Merrigan, Rogers, & Goldberg, 2011; see review: Robinson-O'Brien, Story, & Heim, 2009) and physical activity (Wells, Myers, & Henderson, 2014; Myers & Wells, 2015); and to advance children's science, technology, engineering, math (STEM) learning (Kelley & Williams, 2013; Klemmer, Waliczek, & Zajicek, 2005).

Recent school garden initiatives also relate to the larger movement aimed at fostering children's connection to the natural environment. Children's time spent outdoors has declined in recent decades (Hofferth, 2009; Louv, 2005) as television, computers, online games, and other indoor pursuits have claimed more hours of the day. The trend of children's disconnection from nature is apparent despite the well-documented benefits of nature access and exposure (see reviews Frumkin, 2001; McCurdy, Winterbottom, Mehta, & Roberts, 2010; Wells & Jimenez, in press; Wells & Rollings, 2012). The beneficial effects of children's time in nature include enhanced cognitive functioning (Faber Taylor, Kuo, & Sullivan, 2002; Wells, 2000), better academic performance (Matsouka, 2010), reduced symptoms of Attention Deficit Disorder (Faber Taylor & Kuo, 2009; Faber Taylor, Kuo, & Sullivan, 2001; Kuo & Faber Taylor, 2004), lower likelihood of weight gain (Bell, Wilson, & Liu, 2008), lower rates of myopia (Dirani, Tong, & Gazzard, 2009; Rose et al., 2008), more positive later life environmental attitudes and behaviors (Chawla, 2001; Wells & Lekies, 2006, 2012), and greater personal and psychological resilience (Chawla, Keena, Pevec, & Stanley, 2014; Wells, 2014; Wells & Evans, 2003). Thus, because school gardens are a vehicle for bringing children outdoors and facilitating their connection with nature, extant evidence suggests that the potential benefits of school gardening are broad and myriad.

With the recent resurgence of school gardens, there is particular interest in assessing the effects of gardens on children's behavior and learning (Blair, 2009). Studies examining the effects of students' engagement with school gardens on learning or academic outcomes have focused on science, math, and language arts[1] as well as overall grade point average (see reviews Berezowitz, Bontrager Yoder, & Schoeller, 2015; Williams & Dixon, 2013). And yet, despite numerous studies, the strength of the evidence assessing school gardens' effects is impaired due to methodological limitations such as: modest sample sizes, lack of pre-intervention baseline data (pre-tests), failure to include a no-garden control or comparison group, and lack of random assignment to experimental and control groups. In fact, none of the 50 studies reviewed by Williams and Dixon (2013) employed random assignment. These authors note that there is need for greater rigor in the design and execution of studies examining school gardens' effects on academic outcomes. They point out, for example, that 'validity' is seldom mentioned (Williams & Dixon, 2013). Together, the methodological weaknesses compromise most extant studies' internal validity—our ability to conclude confidently that school gardens affect learning. These methodological limitations likely contribute to the fact that research investigating the effects of school gardens on academic outcomes reveals mixed results with some finding no effects or even poorer outcomes among children in garden-based classes compared to those in traditional classes.

Moreover, few studies have examined the role of school gardens among low-income students—a group of particular interest due to disparities in academic achievement based on social class (Lee & Burkam, 2002). In addition, to develop effective interventions, it is important to determine what intervention components and what 'dose' or intensity of gardening activities positively impact science knowledge. However, studies seldom examine the dose–response effects—in other words, whether more substantial independent variables (doses) yield more substantial outcome effects—of school garden interventions or the individual influence of various components of the intervention (e.g. lessons and garden activities).

Given the multifaceted interest in school gardens as an academically beneficial component of the elementary school environment, the current study investigates school gardens' effect on science learning—specifically regarding plant science and nutritional science. The study strives to address many methodological weaknesses apparent in earlier research by employing random assignment to intervention or control with a large sample of youth. We examine the effect of gardens on science knowledge and consider the effect of garden intervention fidelity (GIF) (i.e. robustness) along with intervention components.

This study addresses the following two research questions:

(1) To what extent does a school garden intervention, including garden-based curriculum, result in increases in children's science knowledge related to plants and nutrition?
(2) To what extent does the fidelity (or 'dose') of the garden intervention affect children's science knowledge?

Methods

The Educational Program Intervention

The intervention was delivered by Cooperative Extension educators[2] or classroom teachers and consisted of four components. (1) Raised-bed or container garden kits were provided for each participating class. (2) Educators were given access to an Educational Toolkit of garden-based lessons focused on nutrition, horticulture, and plant science (Barale, in preparation; Healthy Gardens Healthy Youth, 2014). The curriculum toolkit was assembled by a team of extension specialists in nutrition, horticulture, and youth development based on their review of 17 extant evidence-based curricula and their ultimate selection of components from 10 curricula. A total of 40 lessons were provided—20 for grades 2–3, and 20 for grades 4–6. Lessons were delivered approximately weekly, during the school day throughout the intervention period. Typically, a lesson lasted one hour and was taught either in the classroom or in the garden, depending on the activity and weather conditions. Aside from delivering lessons, educators also led garden activities such as planting, weeding, and harvesting (see Figure 2). The curriculum toolkit also included online trainings for the educators themselves. The trainings introduced nutrition and garden concepts found in the lessons and included videos demonstrating the delivery of lessons. (3) Resources provided to the school included information about food safety and related topics. (4) A garden implementation guide was shared to provide information regarding planning, planting, and maintenance throughout the calendar year, gardening during the summer, recruiting volunteers, building community capacity, and long-term program sustainability.

Study Design and Procedure

In this longitudinal, randomized controlled trial, schools were randomly assigned to receive the garden and curriculum intervention or to serve on the waitlist control

Figure 2. Students at Riverhead charter school, Long Island, NY complete lessons and find tomato blossoms in their school garden

group that did not receive gardens and access to the curriculum until the end of the study. Baseline (wave 1) data were collected in Fall 2011 followed by garden implementation (Spring 2012) and three waves of follow-up data collection (late Spring 2012, Fall 2012, and late Spring 2013), during which the garden intervention continued to be delivered. The Cornell University Institutional Review Board deemed this research protocol exempt because the study's interactions with children are educational measures of curriculum implemented.

Schools, Classrooms, and Students

A total of 49 schools in Arkansas, Iowa, New York, and Washington participated in this study at baseline. The schools were not randomly selected; rather, based on their knowledge of their own communities, Cooperative Extension educators approached elementary schools in their area to explore partnership. Initially, approximately 80 schools were contacted. The list of schools narrowed based on eligibility criteria (i.e. could not already have a school garden; had to have at least 50% of students qualifying for the federal free or reduced-price meals (FRPM) program or principal's lack of interest. Once the schools within each of region (including rural, suburban, and urban areas) were selected, they were randomly assigned to intervention or control. Waitlist control schools agreed not to begin gardens until the completion of the two-year study.

The total number of classrooms involved in the study was 151 over the two-year period. Most schools had three classrooms participate in the study (mean = 3.53, SD = 0.98, range 2–6). This article represents one component of the Healthy Gardens, Healthy Youth study examining the effects of school gardens on fruit and vegetable (FV) intake, FV preference, STEM self-efficacy, and related outcomes.

The student participants in this study were children in grades 2, 4, and 5 (ages 6–12 years) at the start of the study.

Instruments

Science knowledge: knowledge of plant science and nutritional science. The dependent variable, science knowledge, was operationalized using a 7-item multiple-choice questionnaire selected from the University of Missouri (UM) 'Eating from the Garden Curriculum' survey. The instrument was developed by the UM nutrition and evaluation specialists and pilot tested for clarity and comprehension with elementary age children (K. Elliott, personal communication to KB, October 2012). The content validity of the instrument was established by the Healthy Gardens, Healthy Youth curriculum development team who selected it based on both their knowledge of the scope of the lessons in the Educational Toolkit (Healthy Gardens, Healthy Youth, 2015) and their familiarity with the cognitive abilities and reading levels of children in grades 2–6. The Knowledge of Plant Science and Nutritional Science Questionnaire is shown in Table 1. A child's score is the total number of correct answers. The measure was administered in the classroom, with items read aloud by the teacher or extension educator, with a research assistant or teacher's aide present to assist or clarify, as needed. The instrument has been validated using known groups construct validation comparing the scores of 5th grade students (age 10–11 years) with gardens as part of their science education (mean = 5.33, SD = 1.27) to those without (mean = 3.63, SD = 1.12), $t(103) = 7.23$, $p < .001$; and comparing scores of 2nd graders (age 7–8) in a garden-based summer camp (mean = 4.11, SD = 1.17) to those in a non-garden summer camp (mean = 2.29, SD = 1.33), $t(21) = 3.37$, $p < .01$. Test–retest reliability among children aged 7–8 years is $r = .74$.

Garden intervention fidelity. The GIF variable was created to take into account the variability in intervention fidelity or robustness from clasroom to classroom. Due to the scope of the intervention (involving 151 classrooms across 4 states), there was variability in intervention fidelity. Reasons for the variability included varied levels of interest among classroom teachers, differential school commitment sometimes due to a change in principal, the demands and time constraints of the school's required curriculum delivery, concern that garden activities would interfere with achieving academic goals, and weather. In one region, a Spring hurricane delayed planting.

GIF was operationalized based on 'garden records' completed by Extension educators regarding each class that received the garden intervention. The total GIF ('GIF-Sum') included the number of lessons delivered to the class, the number of FV planted, the number of FV harvested, and the number of methods through which FV were distributed (e.g. eaten as a snack in the garden, sent home, shared with cafeteria), aggregated across the three waves of the intervention. Similarly, to examine the influence of the lessons and the garden components of the intervention independently, two GIF subscales were created: *GIF-Lessons* (the number of lessons delivered) and *GIF-Garden* (the number of FV planted, FV harvested, and methods of FV

Table 1. Instrument measuring knowledge of nutrition and plant science

1. People and plants need
   a. Water
   b. Food
   c. Air
   d. All of the above[a]
2. Which nutrient supplies our bodies with energy?
   a. Fiber
   b. Carbohydrates[a]
   c. Water
   d. Vitamins
3. Which part of the plant are we eating when we eat broccoli?
   a. Flower[a]
   b. Leaf
   c. Root
   d. Bulb
4. When looking at a food label, which nutrient do we want to see a lot of?
   a. Sodium
   b. Fat
   c. Calcium[a]
   d. Sugar
5. Which part of the plant uses the sun's energy to make food?
   a. Root
   b. Stem
   c. Leaf[a]
   d. Flower
6. Which item is not an ingredient used to make compost?
   a. Dried leaves
   b. Fruit and vegetable scraps
   c. Rocks[a]
   d. Water
7. Which part of the plant pulls water and other nutrients from the soil?
   a. Stem
   b. Leaf
   c. Root[a]
   d. Seed

[a]Indicates correct response.

distribution). A categorical variable based on quartiles was constructed for each of the three GIF variables to capture the range from no intervention (level 1) to a very robust intervention (level 4). As summarized in Table 2, level 1 for all GIF variables represented no intervention being delivered. Therefore, level 1 comprises classes assigned to the intervention group that failed to deliver the intervention (or failed to deliver a component of the intervention) as well as the waitlist control (i.e. non-intervention) classes. Level 2 represented a modest intervention with a few lessons taught (mean = 3.44, range 1.00–5.00), some FV planted, harvested, and distributed (mean 4.31, range 1.00–6.67), and a modest overall GIF-SUM (mean = 7.68, range 1.00–14.33). Level 3 represented a fairly strong intervention with, on average, 9.42

Table 2. GIF variables derived from quartiles ($N = 151$ classrooms)

	Level 1 No intervention	Level 2 Modest intervention	Level 3 Strong intervention	Level 4 Very robust intervention
	Mean (SD) range	Mean (SD) range	Mean (SD) range	Mean (SD) range
GIF-Lessons	0 $n = 54$	3.44 (1.41) 1.00–5.00 $n = 18$	9.42 (1.74) 6.00–12.00 $n = 40$	16.49 (2.34) 13.00–20.00 $n = 39$
GIF-Garden	0 $n = 55$	4.31 (1.93) 1.00–6.67 $n = 18$	12.81 (3.13) 7.00–17.33 $n = 31$	27.85 (8.53) 17.67–43.33 $n = 47$
GIF-Sum	0 $n = 54$	7.68 (4.20) 1.00–14.33 $n = 19$	22.33 (4.83), 15.00–30.33 $n = 29$	42.45 (8.23) 30.67–55.00 $n = 48$

lessons delivered (GIF-Lessons range 6–12), a mean of 12.81 FV planted, harvested, and distributed (GIF-Garden range 7.00–17.33), and GIF-SUM mean 22.44 (range 15.00–30.33). Finally, level 4 represented the highest level of fidelity with a mean of 16.49 lessons delivered (GIF-Lessons range 13.00–20.00), on average, more than 25 FV planted, harvested, and distributed (GIF-Garden mean = 27.85, range 17.67–43.33), and a GIF-SUM mean score of 42.45 (range 30.67–55.00).

Data collection was carried out by trained Cooperative Extension educators based in counties throughout the four participating states.

Participant Response Rate

In Fall 2011, 3,061 students in 49 schools (1,622 students in 25 intervention schools and 1,439 students in 24 waitlist control schools) completed baseline questionnaires. Follow-up questionnaires were administered in Spring 2012, Fall 2012, and Spring 2013. Of the 3,061 students who completed baseline questionnaires, 91% or 2,794 students also completed at least one follow-up questionnaire (1,299 students (90%) in waitlist control schools and 1,495 students (92%) in intervention schools). Of the 24 control schools, 23 (96%) were included in the final analysis along with 24 of the 25 intervention schools (96%). One control and one intervention school were eliminated from the study because they decided not to participate. The total number of schools analyzed was 47; total students 2,794.

Statistical Analysis

Preliminary analyses (i.e. χ^2 and t-tests) were conducted to assess demographic differences between intervention and control at the school and student level.

The first model, summarized in Table 3, included treatment (control versus intervention), sex of child, and wave (1–4) as fixed classification factors; the interactions among these factors; states as an additional fixed classification factor; and individuals and classrooms as levels of random classification factors. This model addresses Aim 1 —examining the main effect of the garden intervention on children's knowledge of plant science and nutrition, without considering the fidelity of the intervention delivered within each elementary classroom.

A second set of models (see Table 3) examined Aim 2, the influence of fidelity. In each of three final models, a fidelity variable was substituted for the treatment classification factor to capture the dose–response relation of the intervention with outcomes. The three four-level fidelity variables were (1) overall GIF, 'GIF-sum'; and the two GIF subscales: (2) GIF-lessons, and (3) GIF-garden. Each of the three models included a fidelity variable, sex of child, and wave (1 versus 4) as fixed classification factors; the interactions among these factors; states as an additional fixed classification factor; and individuals and classrooms as levels of random classification factors. In these models, which include intervention fidelity, the comparisons were restricted to wave 1 versus wave 4. This is because the fidelity variables were constructed using all fidelity data through wave 4, and it is not temporally logical to use data from, for example, wave 4 in predicting an outcome at wave 2 or 3. We did examine other models with different construction of fidelity, but the models presented here best represent the results. We also examined models in which fidelity was included in quantitative form, but again, this did not add to the understanding of results.

In both of these sets of models (addressing Aim 1 and Aim 2), the interaction of states with the other fixed factors is excluded to be able to achieve stability in the computational estimation. We also examined models including child ethnicity and grade.

Analysis was carried out in general linear mixed models. An unstructured error assumption was used, and denominator degrees of freedom were computed by the

Table 3. Summary of analytic strategy, using general linear mixed models

Aim 1: To what extent does a school garden intervention result in increases in children's science knowledge?

- Fixed factors: treatment (T), sex (S), wave (W), states
- Interactions: TxS, TxW, SxW
- Random factors: individuals, classrooms

Aim 2: To what extent does the fidelity of the garden intervention affect children's science knowledge?

- Fixed factors: GIF (G),[a] sex (S), wave (W), states
- Interactions: GxS, GxW, SxW
- Random factors: individuals, classrooms

[a]Three models are examined—one for each of the GIF variables: GIF-sum, GIF-lessons, and GIF-garden.

first-order Kenward–Roger method. The key test in the first model (without GIF) is the test of the interaction of treatment by wave. We partitioned from this interaction pre-specified contrasts of interest—specifically, first, the test of treatment versus control by wave 1 versus waves 2, 3, and 4 (a 2×2 contrast) and second, the test of treatment versus control by wave 1 versus wave 4 (also a 2×2 contrast). Table 5 shows the means and probabilities for these contrasts. In the three fidelity models, the key tests are contrasts of the four fidelity levels, including a test of linearity.

Results

Descriptive Statistics

The 47 elementary schools available for analyses were high-needs schools, with an average of 66.83% of the children participating in FRPM at baseline.

Table 4 summarizes the participant characteristics ($n = 3{,}061$). At baseline (Fall 2011), the participating children were 1,525 2nd graders and 1,536 4th and 5th graders; 50.4% were girls. The average age of participating children in the intervention schools was 8.34 years and in the control schools, 8.22 years. The majority (50.5%) of participating children were white; 20.9% African-American, 15.1% Hispanic, 4.3% Asian, and 9.2% Native American, multi-racial or 'other'. Analyses indicate no significant demographic differences between intervention and control groups with respect to grade, gender, and ethnicity. The groups do differ significantly, however, with respect to age, with a mean of 8.34 and 8.22 for intervention and control, respectively.

Do School Gardens Affect Children's Science Knowledge?

We first examined the hypothesized main effect of school gardens on science knowledge. As shown in Table 5, results indicated that compared to children in the control group, children in the school garden intervention showed a greater increase in science knowledge from wave 1 to waves 2, 3, 4 ($p < .0001$). On average, the garden intervention group increased from 3.20 out of 7 correct answers to 3.74 correct answers while the control group increased from 3.26 correct answers at baseline to 3.50. In addition, differences between intervention and control are slightly greater when comparing wave 1 to wave 4 (than when comparing wave 1 versus waves 2, 3, 4). Also shown in Table 5, analyses reveal a greater increase for children who received the intervention than control group children ($p < .0001$). On average, the garden intervention group increased from 3.20 out of 7 correct answers at baseline (wave 1) to 3.84 correct answers at the end of the intervention (wave 4) while the control group increased from 3.26 correct answers at baseline to 3.43 in wave 4.

Recognizing the considerable classroom-to-classroom variability with which the intervention was delivered, next we take into account the GIF at the classroom level, allowing assessment of the dose–response effect of first, the intervention as a whole (GIF-Sum); and then, the individual intervention components (lessons and garden) on science knowledge.

Table 4. Participant characteristics at baseline

	Intervention $n = 1{,}622$		Control $n = 1{,}439$		Total $n = 3{,}061$		Significant difference I and C[a]
	n	%	n	%	n	%	
Grade							0.767
Lower (2nd)	804	(49.6)	721	(50.1)	1,525	(49.8)	
Upper (4th/5th)	818	(50.4)	718	(49.9)	1,536	(50.2)	
Gender[b]							0.074
Boy	780	(48.1)	738	(51.3)	1,518	(49.6)	
Girl	842	(51.9)	700	(48.7)	1,542	(50.4)	
Age (at baseline)[c,d]							0.005**
6	10	(0.6)	11	(0.8)	21	(0.7)	
7	597	(37.0)	543	(37.9)	1,140	(37.4)	
8	201	(12.4)	174	(12.2)	375	(12.3)	
9	478	(29.6)	529	(36.9)	1,007	(33.0)	
10	296	(18.3)	169	(11.8)	465	(15.3)	
11	29	(1.8)	5	(0.3)	34	(1.1)	
12	4	(0.2)	1	(0.1)	5	(0.2)	
Ethnicity[e]							0.116
White	652	(49.0)	650	(52.1)	1,302	(50.5)	
African-American	248	(18.6)	292	(23.4)	540	(20.9)	
Hispanic	215	(16.2)	174	(13.9)	389	(15.1)	
Asian	54	(4.1)	57	(4.6)	111	(4.3)	
Native American	16	(1.2)	9	(0.7)	25	(1.0)	
Multi-racial	19	(1.4)	8	(0.6)	27	(1.0)	
Other	127	(9.5)	58	(4.6)	185	(7.2)	

Note: Values are numbers (percentages) ($n = 3{,}061$).

[a]Chi-square analyses were used to compare the differences between intervention and control groups.

[b]Gender was missing from one child (control school), table shows valid percentages (intervention $n = 1{,}622$, control $n = 1{,}438$, total $n = 3{,}060$).

[c]t-Test analyses were used to compare the differences between intervention and control groups.

[d]Age (at baseline) was missing from 14 children, table shows valid percentages (intervention $n = 1{,}615$, control $n = 1{,}432$, total $n = 3{,}047$).

[e]Ethnicity was missing from 482 children, table shows valid percentages (intervention $n = 1{,}331$, control $n = 1{,}248$, total $n = 2{,}579$).

$^{**}p < .01$.

Does the Effect of School Gardens on Science Knowledge Vary by Intervention Fidelity?

The second research question examined whether the fidelity of the garden intervention had an effect on science knowledge. Results, summarized in Table 6 and Figure 3, indicated that higher scores on GIF-Sum (the overall GIF variable), were associated with significantly higher science knowledge scores. Among classrooms with no intervention (GIF-Sum level 1), the science knowledge score increased 0.15 from baseline

Table 5. Science knowledge score, by treatment and pre-garden (wave 1) to post-garden (waves 2, 3, and 4) and wave 1 versus wave 4

	Intervention $n = 1{,}622$		Control $n = 1{,}439$			
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	(Intervention—control)	
	Pre (W1)	Post (W2–W4)	Pre (W1)	Post (W2–W4)	Mean difference	p-Value
Science knowledge ($n = 2{,}794$) $t(6{,}613) = 5.59$	3.20 (.06)	3.74 (.07)	3.26 (.07)	3.50 (.07)	+0.17 (.01)	<.0001
	Pre (W1)	Post (W4)	Pre (W1)	Post (W4)		
Science knowledge ($n = 1{,}712$) $t(6{,}613) = 6.71$	3.20 (.06)	3.84 (.07)	3.26 (.07)	3.43 (.07)	+0.47 (.01)	<.0001

to follow-up. On average, classes with a modest intervention (GIF-Sum level 2) increased their science knowledge by 0.49, while those with a strong intervention (GIF-Sum level 3) increased by 0.53; and among those receiving a very robust garden intervention (GIF-Sum level 4), science knowledge increased by 0.78.

Analyses with fidelity subscales, GIF-Lessons and GIF-Garden, further revealed significant differences among fidelity levels (1, 2, 3, and 4) from baseline to follow-up, indicating the effect of intervention components. Both GIF-Lessons and GIF-Garden were positively associated with science knowledge. As shown in Table 6, science knowledge scores increased by 0.17 from baseline to follow-up for those receiving no intervention (GIF-Lesson level 1), while science knowledge scores increased by 0.53, 0.58, and 0.74 for classes receiving modest, strong, and very robust lessons, respectively (i.e. GIF-Lesson levels 2, 3, and 4). Similarly, science knowledge increased, on average, by 0.16 among those receiving no intervention (GIF-Garden level 1) and by 0.54, 0.49, and 0.79 for those who received modest, strong, and very robust garden components of the intervention, respectively (i.e. GIF-Garden levels 2, 3, and 4).

Discussion

Findings of this study indicate that the school garden intervention, consisting of both lessons and a garden for each participating classroom, had a positive effect on children's knowledge of plant science and nutritional science. The intervention group's gain, though modest (from 46% to 53% correct answers, on average), was significantly greater than the control group's gain (from 47% to 50% correct) over the two-year study. This main effect, however, is dampened by the inclusion of classrooms that implemented little or no intervention—by delivering few of the lessons and/or by planting, harvesting, and distributing few fruits and vegetables.

Table 6. Science knowledge, by treatment, GIF (GIF-Lessons, GIF-Garden, and GIF-Sum) and pre-garden (wave 1) to post-garden (wave 4)

	Pre (W1) Mean (SE)	Post (W4) Mean (SE)	(W4–W1) Mean difference (SE)
Fidelity			
GIF-Lessons 1	**3.21** (.06)	**3.38** (.07)	**0.17** (.05) ($p = .0005$)
GIF-Lessons 2	**3.05** (.10)	**3.58** (.13)	**0.53** (.11) ($p < .0001$)
GIF-Lessons 3	**3.27** (.09)	**3.85** (.09)	**0.58** (.08) ($p < .0001$)
GIF-Lessons 4	**3.12** (.10)	**3.86** (.10)	**0.74** (.08) ($p < .0001$)
GIF4–GIF1	−0.09 (.11) ($p = .382$)	0.48 (.11) ($p < .0001$)	−0.57 (.09) ($p < .0001$)[a]
GIF linear	−0.06 (.34) ($p = .865$)	1.70 (.36) ($p < .0001$)	−1.77 (.30) ($p < .0001$)[a]
GIF-Garden 1[b]	**3.22** (.06)	**3.38** (.07)	**0.16** (.05) ($p = .0004$)
GIF-Garden 2	**3.24** (.11)	**3.78** (.13)	**0.54** (.11) ($p < .0001$)
GIF-Garden 3	**3.07** (.09)	**3.56** (.10)	**0.49** (.09) ($p < .0001$)
GIF-Garden 4	**3.20** (.09)	**3.99** (.09)	**0.79** (.07) ($p < .0001$)
GIF4–GIF1	−0.02 (.10) ($p = .835$)	0.61 (.11) ($p < .0001$)	−0.63 (.09) ($p < .0001$)[a]
GIF linear	−0.23 (.34) ($p = .492$)	1.60 (.36) ($p < .0001$)	−1.84 (.29) ($p < .0001$)[a]
GIF-Sum 1[c]	**3.22** (.06)	**3.37** (.07)	**0.15** (.01) (.001)
GIF-Sum 2	**3.25** (.09)	**3.74** (.11)	**0.49** (.10) ($p < .0001$)
GIF-Sum 3	**3.08** (.08)	**3.61** (.09)	**0.53** (.08) ($p < .0001$)
GIF-Sum 4	**3.20** (.09)	**3.98** (.09)	**0.78** (.07) ($p < .0001$)
GIF4–GIF1	−0.01 (.10) ($p = .903$)	0.61 (.11) ($p < .0001$)	−0.62 (.09) ($p < .0001$)[a]
GIF linear	−0.21 (.34) ($p = .537$)	1.70 (.36) ($p < .0001$)	−1.91 (.29) ($p < .0001$)[a]

[a]Key tests of fidelity are in table entries that are the intersection of (GIF4 versus GIF1) × (W4 versus W1) and of (GIF linear) × (W4 versus W1). These are tests partitioned from the overall fidelity × wave interaction. GIF linear specifies a linear relation over four fidelity levels.

[b]GIF-Garden is FV planted, harvested, and distributed combined.

[c]GIF-Sum is lesson total and garden composite combined.

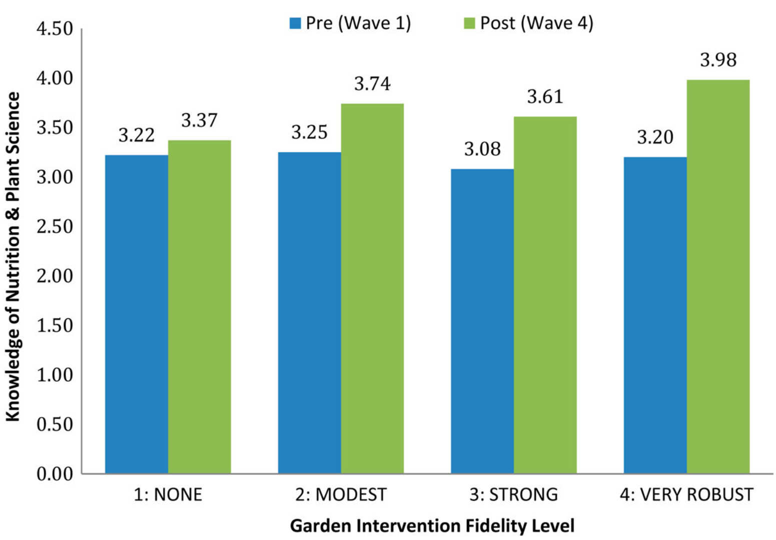

Figure 3. The effects of GIF-Sum level on science knowledge

Examining overall GIF and the two fidelity subscales provides a clearer view of the effect of the school garden intervention on children's science knowledge and suggests a dose–response effect of school gardens on children's science knowledge. Among children experiencing a very robust garden intervention (as indicated by GIF-Sum), knowledge scores increased 0.78 out of 7 points—equivalent to an increase from 46% to 57% correct. This gain contrasts with smaller increases in science knowledge over the two-year period among children who received no intervention (an increase of 0.15/7 points, from 46% to 48% correct), a modest intervention (an increase of 0.49/7, from 46% to 53%), or a strong intervention (an increase of 0.53/7, from 44% to 52%). The pattern of children's gains in science knowledge reveals a dose–response relation with intervention fidelity. Stronger overall garden interventions yield greater science learning.

This study has several methodological strengths. To our knowledge, this is the first randomized controlled trial or true experiment to examine the effects of school gardens on children's science knowledge. The research design—employing random assignment to intervention or waitlist control group, with baseline and follow-up measures across a two-year period—ensures strong internal validity and provides insight into the effects of school gardens on children's science knowledge. The two-year duration of the study is an asset because it allows for examination of relatively long-term effects rather than merely immediate or very short-term learning over weeks or months. The study's geographical range across four US states and regions enhances its external validity. Inclusion of a quantitative measure of GIF illuminates the dose–response effects of the intervention and allows for the differentiation of weak versus strong, rigorously administered interventions. In addition, the focus on low-income communities, where academic disparities in the USA are greatest (Lee & Burkam, 2002), ensures the practical relevance of this study.

It should be noted that while results indicate that there is both a statistically significant main effect of school gardens on children's science knowledge, and a significant dose–response pattern of garden fidelity on science knowledge, the impact of the garden intervention on children's learning, as captured in this study, is very modest. Even in classes where students received very robust interventions, at the end of the two-year intervention, children, on average, answered only 57% of questions correctly. Moreover, the control group does show some improvement, perhaps due to their normal learning and maturation over the two-year period, but not as much as the intervention group.

The findings of this study are generally consistent with prior research. For example, similar to the current study, Smith and Motsenbocker (2005) used pre-test and post-test measures with both a control and an intervention group and found that the garden intervention group's science knowledge improvement was modest (from 39% to 42% correct) but was greater than that of the control group (from 36% to 38% correct). In their review of the literature, Williams and Dixon (2013) report that of 15 studies examining the effects of school gardens on science learning, 14 (or 93%) report a positive effect. For example, Klemmer et al. (2005) reported slightly higher science scores for elementary school children involved in a school garden program as part of their science curriculum compared to children who received the traditional science education without a garden. However, because the study by Klemmer et al. employed a post-test only design, with no pre-test (baseline) measures, it is not possible to draw a clear conclusion regarding the effects of the garden since the groups may have differed at baseline. Pigg, Waliczek, and Zajicek (2006) also used a post-test only design, but found no significant difference in science scores between the school garden intervention group and the no-garden control group.

It is also worth noting that while the science knowledge scores of students in the current study were quite low (i.e. on average, 44–57% correct), these scores are comparable to percent correct scores reported in prior studies of science knowledge that is, 45–60% in Klemmer et al. (2005); 36–42% in Smith and Motsenbocker (2005); and 55–59% in Pigg et al. (2006). Thus, the low scores of students in this study seem not to be idiosyncratic, but rather, consistent with prior evidence and with reports of poor STEM preparedness among US students (Lemke et al., 2003; National Science Foundation, 2007), particularly among those from low-income communities.

While this study has made methodological strides in its examination of the effects of school gardens, it is not without limitation. The focus on children in underresourced communities in only four US states may limit the generalizability of the findings to other groups, states, or countries. Second, although variability in the delivery of the intervention was quantified through GIF, there are undoubtedly nuanced aspects of the intervention delivery that were not thoroughly captured (e.g. teacher enthusiasm and skill; parental involvement; community support; exact number of hours spent outdoors; etc.). In addition, although the tool employed to measure science knowledge was assessed for content validity by the curriculum development team and for construct validity based on known groups, further psychometric testing of this measure would be valuable. Moreover, a more elaborate measure, with more items, may have provided a better representation of the broader construct of ‘science knowledge’.

Conclusions & Future Research

Findings from this study indicate that school gardens have a significant, though modest, positive effect on science knowledge among elementary school children in low-income communities. In classrooms with particularly high fidelity garden interventions, changes in science knowledge from baseline to follow-up were greater than in classrooms with weaker garden interventions.

The results of this study suggest that school gardens convey a fairly modest benefit to low-income children in terms of gains in science knowledge. As principals, teachers, and school districts weigh the value of school gardens, however, these modest results should be viewed within the context of the broader benefits of time outdoors in general, and the school gardens’ unique potential to affect a wide variety of child outcomes. While there is a need for further research to more clearly identify the synergistic benefits of school gardens, we do know that time outdoors, experiential learning, and engagement with nature have myriad benefits in terms of boosting levels of physical activity, bolstering cognitive functioning, and fostering collaboration (see reviews Blair, 2009; McCurdy et al., 2010; Wells & Jimenez, in press). Given the current climate within US public schools characterized by a time-pressured, testing-focused environment, there is a need for continued research to assess whether school gardens do indeed have complementary and synergistic benefits (Berezowitz et al., 2015; Wells et al., 2014). In the current study, although teachers were typically excited about the gardens, barriers were presented by their sense of time pressure. Despite the curriculum being aligned with academic standards, some teachers perceived the garden-based lessons as an 'extra' activity. If school gardens truly yield multifaceted beneficial outcomes that foster the development of the 'whole child' (i.e. contributing to social, academic, cognitive, and health outcomes), then gardens can be embraced for more integrated endeavors rather than gardens being viewed as competing for limited time and resources.

Additional research might further examine a variety of potential moderator variables influencing the effect of the school garden intervention on science knowledge. Potential moderators include the content and nature of the lessons, the physical characteristics of the garden itself, and the timing of the intervention in children's lives. Specifically, what is the role of various lesson types in conveying knowledge of plant science and nutritional science? Do hands-on lessons and/or lessons that involve planting seeds or seedlings or tasting fruits and vegetables have a greater impact than other kinds of lessons? These studies can help to equip practitioners with tools to more effectively address the income, racial, and ethnic achievement gaps that pervade the US educational system, and to enhance the preparedness of low-income and ethnic minority youth for science, technology engineering, and math (STEM) careers. Studies conducted in the future might employ a more elaborate measure of science knowledge and might, in a longitudinal study, sample items from a larger pool of items rather than repeating items. In addition, to inform the development of garden interventions, future research might examine which aspects of science learning are mostly strongly affected—plant science or nutritional science—by a school garden intervention. Data from the current study, for example, suggest that plant science items might be more strongly affected than nutritional science items. Further research might also assess children's attitudes and behaviors regarding science learning in addition to their change in science knowledge.

Future studies might also build on the findings of the current study with respect to garden fidelity to understand more clearly the dose–response effects of school garden interventions on children's science knowledge and related outcomes. Future research might also examine the effect of the curriculum lessons on students' learning, independent of the effect of the garden activities (and vice versa). Moreover, clarity regarding the necessary nature and scope of school garden interventions will contribute to the development of more effective and efficient future intervention strategies.

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Notes

1. 'Language arts' in the USA refers to English language and literature.
2. Cooperative Extension is a program that exists in each of the 50 US states as a mechanism to share knowledge in order to promote health and well-being. The academic center of extension is the more than 100 land-grant colleges and universities throughout the US Cooperative Extension educators, based in county offices in each state, disseminate information to their communities and collaborate with academic researchers, as in this study.

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