Diversity and the Promise of Science in the Learning Gardens: Students’ Motivation, Achievement, and Science Identity in Low-Income Middle Schools

Paper presented at the
American Educational Research Association Annual Meeting,
San Antonio, Texas, April 2017

Authors:

Dilafruz Williams, Ph. D., Professor, Leadership for Sustainability Education, Graduate School of Education, Portland State University

Heather Brule, Research Associate/Doctoral Candidate, Psychology, Portland State University

Sybil Kelley, Ph.D. Assistant Professor, Leadership for Sustainability Education/ Curriculum and Instruction, Graduate School of Education, Portland State University

Ellen Skinner, Ph.D. Professor, Psychology, Portland State University

Contact: Dilafruz Williams, williamsdi@pdx.edu, Portland State University, Portland, OR 97201
Abstract

Science in the Learning Gardens (SciLG) is a program that proposes to address two inter-related educational needs that are well documented: underrepresentation of racial and ethnic minority (henceforth, minority) students in science; and inadequacies of curriculum and pedagogy to address their cultural and motivational needs. Funded by the National Science Foundation\(^1\), SciLG is a partnership between Delta Public Schools and Delta State University\(^2\). By focusing on 6\(^{th}\) through 8\(^{th}\) grade science that aligns with Next Generation Science Standards and that uses school gardens as the milieu for learning, the project also studies the factors that support success of a largely diverse student population using the motivational framework of Self-Determination Theory. This study of 113 sixth grade students and their three science teachers at two Title 1 urban schools reports the initial findings from an on-going three-year, longitudinal research of SciLG. Longitudinal data were collected in students’ sixth-grade and in the fall of their seventh-grade. A combined measure of students’ gardening experiences (self-reports of belonging, competence, and autonomy, engagement and teacher-reports of re-engagement) predicted four science outcomes: engagement, learning, grades in science class, and academic identity in science. Findings suggest that garden-based activities show promise in fostering not only students’ science-class experiences, but also their actual grades and their interest in pursuing science long-term. This study highlights the role of students’ self-perceptions of being competent, related, and autonomous in the garden, as well as their engagement and re-engagement in the classroom, as potential pathways by which gardening activities in SciLG influence motivation, learning, and academic identity in science.
Introduction

There is growing concern among policy-makers and practitioners alike that despite demographic trends showing an increasing population growth among ethnic and racial minority groups (henceforth, minority), some of these groups—specifically, African-Americans, Hispanics, and Native-Americans—continue to be underrepresented in Science, Technology, Engineering, and Mathematics (STEM) majors in colleges and in STEM careers and professions (Brown & Crippen, 2017; Elliott, 2015; National Research Council [NRC], 2011; President’s Council of Advisors on Science and Technology [PCAST], 2010; Stiles, 2016; U.S. Department of Education [USDE], 2010; Yager & Brunkhorst, 2014). Systemic gaps in opportunities and access to high-quality STEM teaching and programming disproportionately impact low-income and racial minority students (Elliott, 2015; Milner, 2012; Stiles, 2016). These disparities are especially troubling since research shows that marginalization and disengagement from STEM learning starts early, and if students lose interest and do not develop connections to these subjects by the end of middle school, they are less likely to pursue them in higher education (Bathgate, Schunn, & Correnti, 2014; Elliott, 2015; Fraser, Tobin, & McRobbie, 2011; Museus, Palmer, Davis, & Maramba, 2011).

A robust body of research also highlights the inadequacies in the overall teaching received by minority students, resulting in a widening achievement gap between non-white and white students at all grade levels in schools (Bingham & Okagaki, 2012; Howard, 2012). To address these concerns, scholars have called for culturally responsive pedagogy (Babco, 2003; Fordham & Ogbu, 1986; Gay, 2000; Howard, 2012), real-life active learning (Author1, 2012; Hawkins, 2014; Howard, 2012; Hrabowski & Maton, 2009; Williams & Brown, 2012; Yager & Brunkhorst, 2014), and challenging academic activities provided within supportive contexts that facilitate motivation,
engagement, and the development of a positive academic identity (Skinner & Pitzer, 2012; Skinner, Furrer, Marchand, & Kindermann, 2008).

Culturally responsive pedagogy rejects the deficit assumptions and approaches that some educators have historically held about minority students in their classrooms. By considering the multicultural, lived experiences of students as strengths, culturally responsive pedagogy recognizes “the rich and varied cultural wealth, knowledge, and skills that diverse students bring to schools” (Howard, 2012, p. 1). Legitimizing the varied cultural understandings of students, a wide variety of pedagogical and inclusive strategies are used to help bridge the culture of science with students’ everyday experiences (Cutter-Mackenzie, 2009). Teacher-student relationships are critical components of culturally responsive learning environments (Brown & Crippen, 2017; Ladson-Billings, 1995), and through these relationships, teachers validate and build on students’ prior knowledge and experience, making science relevant and meaningful (Gay, 2000; Howard, 2012). Furthermore, Hawkins (2014) argues that for decades, STEM education has been a realm held exclusively for accelerated, advanced students, yet, when STEM is taught through “real-life explorations that require students to gather and analyze data; to create models; to make observations; to build, test, redesign, and redefine their ideas, all in order to discover a scientific concept or hidden truth…it is riddle-solving at its finest!” (Hawkins, 2014, p. 77). By doing science, students solve problems and mysteries of the natural world, rather than simply memorizing facts.

When combined with culturally responsive pedagogy, self-determination theory (Deci & Ryan, 1985, 2000; Skinner, Furrer, Marchand, & Kindermann, 2008; Skinner & Pitzer, 2012) provides a useful, research-based framework for identifying and developing activities to support the motivation and engagement of minority students in STEM. Social-determination theory (SDT) highlights students’ needs to feel competent and welcome in the
practices of science, and to make connections between science and their own interests and daily lives. Grappling with real-world issues challenges students to learn science by doing science (Hawkins, 2014), and when students are supported in these endeavors by caring educators, they become more engaged and motivated to learn. Challenging students to address authentic problems in their schools and communities allows them to explore their own ideas and questions as they apply their understandings to develop solutions (for examples in practice, see Yager & Brunkhorst, 2014). Further, culturally responsive learning environments include positive teacher-student relationships, value students’ assets, shift power dynamics between educator and learners, and connect learning to students’ lives outside of school. These types of activities and relationships can help students feel more connected to their learning, and in turn increase academic engagement (Author4 et al., 2008, 2009b, 2012; Connell & Wellborn, 1991; Deci & Ryan, 1985, 2000; Fredricks, Blumenfeld, & Paris, 2004; Ryan & Deci, 2016; Skinner et al., 2008, 2009b; Skinner, Chi, & the LEAG, 2012).

This collective body of research points to the important role that educators play in stimulating students’ interests in science. By engaging students in scientific practices, teachers can help them connect their lives to real-world issues, an important aspect of culturally responsive teaching and learning. Nonetheless, implementing culturally responsive education can be challenging for science teachers. Brown and Crippen (2017) note that in particular, teachers often struggle with how to best use students’ lives and experiences outside of school as starting points for teaching and learning. An even deeper challenge can be disrupting power dynamics by redistributing authority and control in the classroom (Brown & Crippen, 2017), an important aspect of supporting students’ ownership over their own learning.

Garden-based educational programs show promise as meaningful, culturally responsive, real-life, supportive contexts for promoting students’ engagement and other important academic
outcomes (Author1, 2013; Blair, 2009; Elliott, 2015; Fusco, 2001; Gayle, 2011; Moore, 1997; Ozer, 2006; Williams & Dixon, 2013). A recent meta-analysis and synthesis of 48 research studies on garden-based learning from 1990 to 2010 showed positive effects on a variety of academic outcomes including science, language arts, and mathematics; and on a variety of outcomes that indirectly support academics including development of self-concept, change in eating habits, and positive environmental attitudes (Williams & Dixon, 2013). The majority of gardens examined in these studies were integrated with science classes (Klemmer, Waliczek, & Zajicek, 2005a; Klemmer, Waliczek, & Zajicek, 2005b; Rahm, 2002; Smith & Motsenbocker, 2005). Of the 40 studies assessing direct learning outcomes, 33 (83%) found positive effects. Fifteen studies using garden-based learning measured science outcomes, of which 14 showed positive effects. For example, in one study, using a sample of 647 students in Grades 3–5 in seven elementary schools in Temple, Texas, Klemmer, Waliczek, and Zajicek (2005b) found that “science achievement of students who participated in a hands-on school gardening program was higher than that of students who did not participate” (p. 448). They concluded: “Hands-on, constructivist learning serves as the main idea behind school garden programs. Gardens can serve as living laboratories in which students can see what they are learning and in turn, apply that knowledge to real world situations” (p. 452). Williams and Dixon (2013) explain, “Soil chemistry, plant taxonomy, plant parts, flower dissection, water properties, seed germination and variety of seeds, insects and other wildlife, ecology and environmental horticulture, and insects and diseases represent a partial list of science themes presented in the research studies” (p. 219).

Taken together, findings showed the potential of garden programs for benefitting academic and academic-related outcomes, especially in science. The integration of garden-based activities may likely be not only an important ingredient for science learning, but also shape students’ engagement and enthusiasm for science in the regular classroom. Cumulatively, engagement in the
garden and in science class may serve as a mechanism of personal transformation in a student’s academic identity, convincing minority students that they are “the kind of person” who is needed and who can succeed in science (Saxton-Authors et al., 2014; Skinner, Chi, & the LEAGAuthor4 et al., 2012).

Science in the Learning Gardens

In light of the challenges of underrepresentation of ethnic and racial minority students in science fields, it is essential to design activities that foster minority students’ perceptions as competent, connected, and autonomous STEM learners. Doing so has the potential to bolster engagement, learning, and identity with the broader STEM fields. Critical to advancing science education for minority students is to engage students with real-life issues via academically challenging activities in science in simple yet profound ways. Garden-based educational programs—often known as Learning Gardens—use school gardens as the milieu for academic learning (Williams & DixonAuthor1, 2013). In low-income schools, often with large percentages of linguistically and racially diverse student populations, learning gardens have the objective of providing connections to life and learning science in ways not typically addressed in classrooms in urban schools in particular (Kelley & WilliamsAuthors, 2013; Williams & BrownAuthor1, 2012).

A program funded by the National Science Foundation¹ called Science in the Learning Gardens (henceforth, SciLG): Factors that Support Racial and Ethnic Minority Students’ Success in Low-Income Middle Schools has been designed to address the needs of youth, as well as to investigate how school gardens might offer a supportive milieu in which to engage them for success and positive outcomes. The research reported here draws upon this program, which provides a garden-based curriculum for sixth through eighth grade students, offered in partnership between Delta State University and Delta Public Schools². The team consists of university faculty
and researchers, community partners, and teachers with expertise in multicultural, garden-based, and science education. This team has utilized a design-based approach to develop a garden-based science curriculum that is aligned with the Next Generation Science Standards (NGSS Lead States, 2013) and with the middle school curriculum already adopted by the school. SciLG uses school gardens as a context for hands-on, experiential, and holistic science learning activities. The program also draws upon the motivational framework of self-determination theory (SDT).

**Curriculum and Instruction**

SciLG addresses the three dimensions of STEM education called for in the *Framework for K-12 Science Education* (National Research Council [NRC], 2012) and the NGSS (NGSS Lead States, 2013)—disciplinary core ideas, cross-cutting concepts, and the practices of science and engineering—and seeks to engage historically marginalized students in meaningful, high-quality science learning. The SciLG team incorporates key elements of culturally responsive pedagogy into curriculum and instruction with the goal of supporting racially diverse students in developing scientific identities and ultimately persisting in STEM pursuits. In particular, SciLG activities provide students with opportunities to engage in practices of science and engineering in a garden-based context. The SciLG curriculum systematizes and connects key concepts and practices in the NGSS with middle school science curriculum, while simultaneously integrating school gardens as a context for science learning. Instructional units incorporate issues such as the impacts of climate change on local food systems through problem solving (engineering design) and explorations in the garden. Contextualizing big issues in a local setting allows students to engage in scientific endeavors in meaningful ways. As an example, Figure 1 highlights the yearlong progression of garden-based instructional units and activities for 6th grade as they were developed and aligned to the classroom curriculum. In this context, Delta Public Schools has adopted the Science Education for Public Understanding (SEPUP) curriculum. The specific SEPUP modules assigned to each grade level
reflect the Delta State’s implementation plans for adopting the NGSS in an integrated manner for middle school (i.e., life science, physical science, and earth science are integrated each year).

Because of the increased emphasis on engineering design in the Framework for K-12 Science Education (NRC, 2012) and the NGSS (NGSS Lead States, 2013), and because challenges routinely emerge in gardens, problem-solving has been an emphasis throughout the SciLG curriculum (see Appendix A for examples). The yearlong curriculum map shown in Figure 1 outlines the 6th grade instructional plans, including three garden-based units and enrichment lessons through the year. The fall instructional unit involved a long-term engineering design project focused on the challenge: “How can we grow more food during the winter?” In this unit, students applied classroom learning about energy to design and build cold frames, testing which design features would yield the best results. The spring unit emphasized an extended investigation exploring how environmental and genetic factors impacted plant growth and survival. Through this investigation, students also learned how interconnected these factors can be, laying the foundation for deeper learning about epigenetics and genetics to be covered in high school. In addition, a unit on weather and climate involved students in collecting weather data all year long. Since there were six different classes of students visiting the gardens on different days and at different times, by the end of the school year, students were able to analyze a large data set to compare and contrast their data to historical trends. Each of these units gave students opportunities to engage in the practices of science and engineering. In particular, students engaged in the practices of developing
explanations and models using evidence.

**Theoretical Framework: Self-Determination Theory**

Self-determination theory (SDT) highlights both curricular and interpersonal factors that help students develop a positive academic identity for science and to engage, persist, and succeed in science. First, they must construct a set of self-appraisals or convictions about themselves, namely, that they are competent or self-efficacious, that they are related to or belong in science, and that they are autonomous and take ownership for their own academic progress (Deci & Ryan, 1985, 2000; see Figure 2). These self-perceptions may be especially important for minority students in academic and STEM settings, where such students have often been subject to the majority culture’s doubts about whether they are sufficiently “talented” for academic and STEM work. Such societal assumptions can perpetuate stereotype threats (Elliott, 2015) and lead students to feel incompetent or unwelcome in science, which can prevent them from developing feelings of ownership, commitment, and identification in these fields (Oyserman, Bybee, Terry, & Hart-Johnson, 2004; Walton & Cohen, 2007). In contrast, positive self-perceptions help promote students’ academic engagement and, in turn, achievement—academic resources that minority students need to be successful in science as well as in all other academic domains (Fredericks et al., 2004; Wigfield, et al., 2015).

These self-appraisals, along with authentic and interesting academic tasks, support students' engagement with learning activities and their resilience in the face of challenges and setbacks, which shapes their learning and achievement. One core definition of academic engagement refers to students’ active, enthusiastic, and sustained cognitively focused participation in challenging academic activities (e.g., Skinner et al. 2009b). In the short-term, students’ engagement predicts their learning, grades, and patterns of attendance, and over the long-term, it predicts students’ achievement test scores, retention, and graduation rates.
Not limited to only white students, research shows that even among heterogeneous ethnic and racial minority populations, and those who are low-income, these connections between engagement and academic functioning hold (e.g., Bingham & Okagaki, 2012; Johnson, Crosnoe, & Elder, 2001).

The years of adolescence are particularly critical for students’ motivation and interest in school. In their comprehensive review of research on achievement motivation, Wigfield and colleagues (2006) identified the transition to middle school as a critical period of development. During this transitional time, students tend to lose interest and become more disengaged in school, and may lose sight of the value of learning. These motivational declines are especially steep for students from low-income, minority, and immigrant families (Graham & Hudley, 2005; Meece & Kurtz-Costes, 2001), and in science and math (Anderman & Young, 1994; Simpson & Oliver, 1990; Vedder-Weiss & Fortus, 2012). Losses in academic motivation during middle school are a serious problem, because they predict poor performance and eventual dropping out from high school (Fredricks et al., 2004). Therefore, creating culturally responsive, experiential, and engaging educational experiences should be particularly important for minority students during middle grades because they often experience steep declines in academic motivation and engagement as they progress to high school (Bathgate et al., 2014; Maltese & Tai, 2010; Wigfield et al., 2015).

When looked at through the lens of SDT, culturally responsive garden-based education shows great potential for increasing students’ levels of academic engagement by supporting their
sense of autonomy, relatedness, and competence (Author4, 2009b, 2012; Deci & Ryan, 1985; Skinner et al., 2009b; Skinner et al., 2012). Empirical support for a self-determination perspective on garden-based education comes from a recent study, which used newly developed measures to examine the concurrent associations among elements of the SDT motivational model (Skinner et al.-Author4, 2012). To capture engagement in the gardens, researchers adapted a published measure of engagement that had been validated with multiple reporters and classroom observations (Skinner et al.-Author4, 2009a) and was based on a review of the engagement literature (Skinner et al.-Author4, 2009b; Skinner & Pitzer, 2012). This study found that both student- and teacher-reports of student engagement in gardening activities were associated with students’ feelings of competence, autonomy, and intrinsic motivation for gardening (Skinner et al.-Author4, 2012).

Probing more deeply into motivation for science, Bathgate and colleagues (2014) explored how the motivational interests of adolescents vary across contexts that might be formal or informal; activities that might be generating, consuming, or analyzing knowledge; and topical explorations in subjects such as astronomy or biology. To develop a better understanding of the multifaceted aspects of motivation in science, these authors focused on constructs such as curiosity, interest, identity, and persistence to identify what types of experiences were most motivating to middle school students. Somewhat surprisingly, they found that students generally demonstrated less interest in hands-on science learning in informal contexts, but did find topical preferences among students (Bathgate et al., 2014). Though not the explicit emphasis of their study, their findings highlighted the nexus between formal and informal contexts, and the potential that intentional planning and programming across in- and out-of-school venues could have for generating and maintaining interest among adolescents at a time when they often lose interest in science and school more generally. Due to their proximity and accessibility, school gardens can serve as spaces to
bridge formal and informal learning and can provide the context for many topical explorations that span disciplinary content areas (Kelley & Williams, 2013). If incorporated into the structure and processes of schools, garden-based education can also help mitigate gaps in access to high-quality out-of-school STEM activities (Elliott, 2015). Having formal and informal learning experiences that are clearly connected could help students see connections and develop interest (Bathgate et al., 2014).

Garden-based programs grounded in activities and teaching practices that are culturally, motivationally, and developmentally responsive have the potential to bolster engagement in science and other core subjects, and may help counteract motivational declines typically observed during the transition to middle school (Eccles et al., 1993; Gottfried, Fleming, & Gottfried, 2001; Harter, 1981; Wigfield, Eccles, MacIver, Reuman & Midgley, 1991). Helping to mitigate typical motivational declines is especially valuable for students who are at risk for underachievement and drop-out. Bringing together tenets of SDT and culturally responsive pedagogy, garden-based education can promote positive teacher-student relationships and can nurture students’ sense of belonging and connection to place, narrowing gaps in opportunities for relevant, high-quality learning for historically underserved students (Elliott, 2015).

SciLG provides practical connections for science learning with the growing school gardens movement nationally and is piloted in two Delta Public Schools that are low-income and have predominantly ethnic and racial minority students, large immigrant and refugee populations, and over 20 languages spoken at home. The defining features of garden-based education — holistic, integrated, experiential learning activities (Author, 2012; Blair, 2009; Ozer, 2006; Williams & Brown, 2012) — are reflected in SciLG to capture students’ interest and engagement. Garden-based science activities that are hands-on, high-quality, culturally-relevant and authentic should foster students’ feelings of having what it takes to succeed
(competence), being welcomed and valued (relatedness), and experiencing science activities as important (autonomy). These self-perceptions are not only necessary for students to be able to engage and learn in science classes, but also for students to be able to develop the positive academic identity in science (i.e. identifying as someone who would like to pursue STEM studies and careers) that will enable them to dedicate their efforts to a STEM pursuit (Saxton et al., Authors, 2014).

**Research**

This study reports the initial findings from a three-year, longitudinal project examining the experiences of racially and ethnically diverse students at the two, low-income urban middle schools who participated in *Science in Learning Gardens* (SciLG). The study uses a set of theoretically-guided survey measures based on SDT (Skinner et al., Author 4, 2012; in press; Saxton et al., Authors, 2014) to tap students’ motivational processes while participating in SciLG activities. These motivational processes focused on students’ self-system perceptions, engagement, and coping/persistence (Author 4, 2012; Connell & Wellborn, 1991; Skinner et al., 2012; see Figure 2).

Measures of motivational processes in garden activities were chosen to capture the experiences and actions that SciLG is designed to facilitate. SciLG activities are hands-on, high-quality, culturally relevant and authentic. Such activities should impact how competent and related students feel in the gardens and how autonomous their reasons are for participating in garden activities. Measures of these three self-system perceptions (hereafter, SSPs) give information about whether the intended pedagogical aspects of the SciLG activities are actually received by students. For example, culturally informed and caring pedagogical techniques are only impactful to the extent that students feel as if they and students like them are welcome and valued while in the garden. In a similar vein, the experiential, NGSS-aligned activities will only support students’
learning and motivation to the extent that students actually invest emotionally and behaviorally while participating in those activities. Thus, we measured students’ reports of their own emotional and behavioral engagement and disaffection in the gardens, examining the extent to which students’ felt they were energized and enjoying themselves during activities, and the extent to which they dedicated their full thoughts and efforts to SciLG tasks. Finally, to see whether the garden activities provided a venue for students to build their persistence and capacity to bounce back when encountering setbacks, students’ science teachers reported on each students’ capacity to re-engage in the face of day-to-day academic challenges.

The primary goal of this study is to establish whether students’ motivational processes in SciLG activities are linked to students’ science outcomes. In future studies, the goal will be to investigate how SciLG activities promote science outcomes by exploring each aspect of the motivational model individually and establishing the processes and pathways by which SciLG activities seem to impact certain science outcomes over time. For this phase of the project, however, the goal is to establish whether the combined motivational processes of the SciLG milieu are linked with students’ science outcomes at all. For this purpose, we represented SciLG motivational processes as a whole by creating an aggregated variable which equally weighted SSPs, engagement (vs. disaffection), and re-engagement in the garden.

We selected four variables as markers of important science outcomes. To establish whether the quality of students’ participation in SciLG was linked to motivation for science in the more typical classroom setting, we examined links between SciLG and students’ effortful, energized participation with learning activities in science class, as captured by students’ reports of their emotional and behavioral engagement and disaffection in science class. To see if SciLG activities were associated with students’ feelings of successful learning in science class, we used students’ reports of what and how much they learned in science. To check students’ perceptions of learning
against their actual achievement, we targeted students’ term grades in science class. Finally, to see if SciLG activities seemed related to our diverse students’ perceptions of themselves as people with interest and capacity to pursue a STEM field, we used students’ reports of their science identity: being someone who belongs in science and who may want to pursue science in college or career.

**Research Questions**

Two research questions probed the linkages of SciLG motivational processes with science outcomes. The first research question tested the associations of the aggregate measures of SciLG motivational processes in the spring of 2015 for 6th grade students’ science engagement, reported learning, grades, and science identity, also collected in the spring. We hypothesized that SciLG motivational processes will significantly and positively predict each of the four science outcomes in the spring. The second research question tested whether motivational processes in the spring were associated with the four science outcomes in the fall of 2015, when the students were in 7th grade. We hypothesized that spring SciLG motivational processes would also significantly and positively predict all four outcomes in the fall.

**Context and Participants**

Like many urban school districts, Delta Public School District, with approximately 50,000 students, continues to struggle with closing the achievement gap between white and non-white students and with its low graduation rate. For this research study, we present data from two highly diverse, Title I (low-income) schools with 82% of students qualifying for free and reduced lunch, where all sixth-grade students took part in SciLG garden-based education classes in the winter and spring of 2015 and again, as seventh-graders, in the fall of 2015. The students’ three science teachers were supported by graduate assistants from Delta State University, integrating science themes in the garden curriculum with hands-on activities in the school gardens for 50-90 minutes.
per week.

All 209 sixth graders at the two schools were invited to participate in the study. Parental consent was received for 129 of the students (61% return rate). Of these students, 113 students had data on at least one predictor and one outcome variable, and were included in the study. Students were 59% female, and were ethnically and racially diverse (25% Asian, 2% Black, 26% Latino/Hispanic, 27% White, 18% Multiple ethnicities, 1% other ethnicities). Students were also linguistically and culturally diverse: English was not the primary home language for 51% of students, which was indicative of the high number of immigrant families at these schools. The most common home languages spoken were Spanish, Vietnamese, Russian, and Chinese; parental consent materials were translated into these languages.

Methods

Data for this study were collected in the spring of students’ sixth-grade year and in the fall of their seventh-grade year. Student surveys were administered in science classes by trained researchers and volunteers, using laptop computers and tablets. Teachers completed paper-and-pencil surveys. Students and teachers rated their agreement with Likert-type survey items on a scale from 1-5 (where 1 was “not at all true for me/this student” and 5 was “very true for me/this student”). Negative items were reverse-coded.

Measures

Motivational processes in the garden.

The independent variable was a combined measure of students’ overall experiences in SciLG gardening activities (31 items). Scales assessing students’ reports of their garden self-system perceptions and garden engagement, and teachers’ reports of students’ garden re-engagement (See Figure 2) were adapted and expanded from a suite of garden motivation measures (Skinner et-
Garden self-system perceptions (SSPs) were computed by averaging student’s scores from scales measuring competence, relatedness, and autonomy. These reflected students’ positive feelings about themselves in relation to the garden activities. Competence was measured using seven items that assessed students’ feelings of being able to be successful at work in the garden (e.g. “I can do good work in the garden”) as well as feeling that activities were beyond students’ capacities (e.g. “I just can’t seem to do the right thing in the garden,” reverse-coded). Relatedness was measured using six items in which students reported their feelings of belonging and acceptance in the garden (e.g. “I feel like a real part of the garden”) or feelings of non-membership (e.g. “Sometimes I feel like I don’t belong in the garden,” reverse-coded). Autonomy was measured using four items that captured students’ sense of doing their garden activities for personally-motivated (rather than externally-motivated) reasons (e.g. “Why do I garden? It makes me feel like I am doing something good for the environment,” “Because in the garden, I have noticed that I am learning important things”).

Garden engagement was measured using a 12-item scale capturing students’ perceptions of their energized and effortful participation in the gardens, assessing both emotional and behavioral participation (e.g. “I look forward to the time we spend in the garden,” “I try hard to do well in the garden”) versus their disaffection (e.g. “Gardening is not all that fun for me,” or “When we are in the garden, I can’t wait for it to be over,” reverse-coded) when participating in SciLG activities. Garden re-engagement was measured with two teacher-report items. Teachers rated their observations of each student as either persisting or giving up when encountering everyday challenges in gardening activities (e.g. “When faced with a difficult garden assignment, this student
just keeps at it”).

**Science outcomes.**

The following dependent variables were measured to explore how students’ experiences in SciLG impacted particular science outcomes.

**Science engagement.**

Students’ energized, effortful participation in science class was measured using a 12-item scale adapted from Skinner, Chi, and the LEAGAuthor4 (2012). Items assessed both emotional and behavioral engagement (e.g. “I pay attention to my science teacher,” “Working on science is interesting”) and disaffection (e.g. “When we work on something in science class, I feel bored,” “I don’t try very hard in science”).

**Science identity.**

A nine-item scale was adapted from a measure of STEM academic identity (Saxton, et.alAuthors, 2014). Students reported their sense of being somebody who would be capable and accepted in the field of science (e.g. “I am the kind of person who belongs in science,” or “People like me don’t get jobs in science,” reverse-coded), and their interest in pursuing a career or studies in science (e.g. “I would like to have a job that uses science”).

**Science learning.**

A seven-item scale was adapted from a measure of science learning in the garden (Skinner-et-al.Author4, 2012). Students’ reported on what they learned in science class (e.g. “We learned how to experiment, observe, and measure,” “I learn how science can help solve real problems”) and how much they felt they learned in science class (e.g. “We learn new things all the time,” or “I
do not learn much in science,” reverse-coded).

*Science grades.*

Students’ spring and fall grades in science class were obtained from school records. These were re-coded to a standard 0-4 scale where A = 4 and F = 0.

**Results**

**Descriptive statistics.**

Means, standard deviations, and scale reliabilities for study constructs can be found in Table 1. All measures demonstrated good scale reliability, with Cronbach’s alpha equal or greater to .90 for all scales. The mean level for the aggregate measure of motivational processes in the garden (\(M = 3.80, SD = .76\)) showed that students and teachers reported, on average, positive processes occurring in the garden. The mean levels for the aggregate and each of its subcomponents were approximately a 4 on the 1-5 scale, indicating that students and teachers reported that positive items were “mostly true” and negative items were only “a little true” (student-reported garden self-system perceptions, \(M = 3.56, SD = .84\); student-reported garden engagement, \(M = 3.94, SD = .80\); teacher-reported garden re-engagement, \(M = 3.90, SD = 1.16\)). These mean levels indicate that the SciLG activities seemed to be successful in providing an opportunity for students to feel competent, related, and autonomous, to engage deeply with learning activities, and to re-engage when encountering setbacks.

Mean levels for all science outcome variables indicated generally positive processes in science, as well. Student-reported science engagement in both the spring (\(M = 3.81, SD = .92\)) and the fall (\(M = 3.82, SD = .82\)) showed that students generally reported that statements about their energized, effortful participation in the science classroom were “mostly true.” Students’ reports of their science identity indicated that students had a mildly positive sense of being someone who would belong in, and be interested in pursuing, a career or studies in science (\(M = 3.20, SD = 1.03\))
in the spring; $M = 3.40, SD = .89$ the next fall). Students endorsed statements about learning specific concepts and learning a lot in science class as “mostly true” in both the spring ($M = 3.83, SD = 1.03$) and the next fall ($M = 3.80, SD = 1.00$). Finally, students had an average “B” grade in science in both the spring ($M = 3.07, SD = .94$) and the next fall ($M = 3.37, SD = .99$).

**Inter-construct correlations.**

As expected, study constructs generally showed significant and positive inter-construct correlations (see Table 2). The aggregate measure of motivational processes in the garden in the spring was significantly and positively correlated with all science outcomes. Correlations among constructs measured at the same time-point were generally stronger than spring-to-fall correlations, and correlations among constructs reported on the survey were stronger than the correlations of survey-report constructs with grades. Motivational processes in the garden showed strong correlations with student-report outcomes in the spring ($r$ values ranging from $.59$ to $.71$) and a moderate correlation with science grades in the spring ($r = .31$). As expected, correlations with science outcomes the next fall followed a slightly weaker but otherwise similar pattern, with moderate-to-strong correlations with student-report outcomes in the fall ($r$ values ranging from $.48$ to $.53$) and a weak correlation ($r = .22$) with science grades in the fall. This pattern of associations indicates that motivational processes in the garden show promise as predictors of all science outcomes in both the fall and the spring.

Intercorrelations among science outcomes showed that the four outcomes were, for the most part, interrelated and yet distinct, capturing different facets of students’ science experiences. Student-report science outcomes in the spring showed strong inter-correlations ($r$ values ranging from $.57$ to $.84$), suggesting a relatively cohesive experience in which students who felt engaged in science class also felt a positive science identity and sense of science learning. Correlations between student-report science outcomes and science grades in the spring were, as expected,
weaker. In the fall, inter-correlations among student-report outcomes were similar to spring inter-correlations, showing strong associations ($r$ values ranging from .58 to .82). Correlations between student-report science outcomes and science grades in the fall, however, were not significant, which could be due in part to the limited power to detect weak associations in a small sample.

Intra-construct correlations from fall to spring were moderate to strong ($r$ values ranging from .36 to .55), indicating that students’ science experiences in the spring were similar, but not identical, to those in the fall, and our two research questions (testing the prediction of outcomes in the spring vs. in the fall) did seem to investigate distinct aspects of students’ experiences.

**Analysis of results related to the research questions.**

To answer the first research question, a series of regression analyses investigated whether students’ motivational processes in SciLG gardening experiences in the spring seemed to transfer back into the science classroom. As hypothesized, motivational processes in the garden in the spring significantly and positively predicted each of the four spring-term science outcomes (See Table 3). Students with more positive motivational processes reported significantly higher levels of engagement in science class ($\beta = .65, p < .001, R^2 = .61$). That is, when students reported feeling more competent, related, autonomous, and engaged in the garden, and their teachers reported that students re-engaged more after difficulties in the garden, those same students reported higher levels of energized and effortful participation with science class activities. Students with more positive motivational processes in the garden also showed higher levels of self-reported science learning ($\beta = .70, p < .001, R^2 = .55$) as well as higher science grades ($\beta = .29, p < .01, R^2 = .08$), indicating both a better sense of learning about science and better actual performance in science class. Finally, when students had more-positive motivational processes in the garden, they reported a stronger science identity ($\beta = .59, p < .001, R^2 = .34$), indicating more interest in pursuing science as a career or field of study and an increased identification as someone who could be accepted and successful
in those pursuits. Thus, in support of our first hypothesis, we found that students’ motivational processes in SciLG activities significantly and positively predicted all four science outcomes in the spring.

Another series of regression analyses were used to examine our second research question, testing whether positive effects associated with garden experiences in the spring persisted over the summer into the next fall. Again, as hypothesized, all four science outcomes in the fall were significantly predicted by garden experiences in the spring (see Table 3). Motivational processes in the spring significantly and positively predicted students’ reports of science engagement in the fall ($\beta = .57, p < .001, R^2 = .26$), as well as their self-reported science learning ($\beta = .56, p < .001, R^2 = .26$) and science grades ($\beta = .23, p = .03, R^2 = .04$) in the fall, and their science identity in the fall ($\beta = .52, p < .001, R^2 = .21$). That is, in support of our second hypothesis, when students had higher levels of competence, relatedness, autonomy, engagement, and re-engagement in the spring of 6th grade, they tended to be more engaged with learning activities in their 7th grade science classrooms, as well as reporting learning more in those classrooms, reporting more of an identity as somebody who belongs in science as a field, and actually earning better grades in science class.

**Discussion**

The SciLG curriculum is aligned with the NGSS and designed to be culturally responsive to the student population. The project and research participants include students from two highly-diverse, largely low-income middle schools in an urban district in Delta state. This quantitative study explored the extent to which the hands-on, experiential gardening activities in SciLG supported students’ motivational processes and science outcomes, both concurrently and over time.

When examining the study’s first cohort of students in the spring of their 6th grade year, descriptive statistics suggested that SciLG activities were successful in promoting high-quality
motivational processes in the garden, with students and teachers generally endorsing positive items and disagreeing with negative items when asked about students’ self-perceptions, engagement, and re-engagement in gardening activities. Findings related to the first research questions showed that a combined measure of these motivational processes in SciLG gardening activities was a significant and positive predictor of science-class engagement, learning, grades, and science identity. These effects offer support for the idea that students’ experiences with SciLG activities in the garden may transfer back into the science classroom (via grades, learning, and motivation) and help students identify with the scientific and STEM fields at large.

Findings for the second research question showed that sixth graders’ spring SciLG gardening experiences also significantly predicted their four science outcomes in the fall as seventh graders. That is, despite adjourning for summer vacation and entering new science classrooms, it seemed that students’ spring gardening experiences may have served as positive resources for their science motivation, learning, achievement, and science identity as they began the next school year.

These findings from the first phase of a three-year longitudinal study suggests that learning gardens show promise in having the potential to positively impact students’ success in, and connection to, science. This research provides evidence that participation in a culturally responsive, NGSS-aligned garden-based program not only fostered students’ positive views of themselves in the garden and their engagement and persistence in the gardens, but also their engagement, learning, grades, and identity in their science classes. This empirical evidence supports the assumptions embedded in SciLG—specifically that involving middle school students in authentic, real-world endeavors that have cultural and personal relevance beyond school will not only be engaging, but will also help students learn science with understanding.

Although promising, this study has some limitations. First, the relatively small sample size limits the generalizability of findings to students whose parents did not give permission, as well as
to other schools and samples. As a result, findings should be interpreted accordingly. Similarly, because a small sample limits power to detect effects, replication (in other cohorts and time points within this sample as well as in other schools) is necessary to determine whether the associations of garden motivational processes and science outcomes are stable and enduring. For example, spring motivational processes in the garden predicted fall science grades at a p-value of .03, which is well under our cut value of p = .05, but with 8 tests performed, any test with a p-value over .0125 must be considered as a tentative result. This study is not experimental and does not control for prior levels of outcome variables; therefore, results are correlational rather than causal. In other words, it could perhaps be that students with positive motivational processes in the garden already had a history of positive science outcomes for some unmeasured prior reason, and the pattern of positive effects simply continued as it would have with or without SciLG activities.

Another limitation to this study is that the composite independent variable looks at the overall set of motivational processes students have in the garden as a whole, but does not distinguish whether specific aspects of garden experiences predict particular garden outcomes. For example, perhaps some specific aspect of students’ self-perceptions in the garden is the driver of the relationship with academic identity in science, or perhaps teachers’ reports of re-engagement in the garden drives the relationship with student science grades. In ongoing studies, we are following this cohort into their 7th and 8th grade years, with a focus on detecting the processes by which SciLG gardening activities might support changes in students’ science outcomes.

Conclusions

As concern for social justice is growing based on the achievement gap among African-American, Native-American, Hispanic students and their White and Asian peers, the growing school garden movement provides an opportunity to tip the scales by engaging students in
authentic, real-world learning of science and pique their interests in science with holistic garden-based learning (Kelley & Williams, 2013). This study highlighted the role of students’ views of themselves as competent, related, and autonomous in the garden, as well as their engagement and re-engagement in the garden, as potential pathways by which gardening activities can shape science motivation, learning, and academic identity in science. As Museus et al. (2011) articulate, there is a sense of urgency to ensure success in school and participation in science fields, particularly for racial and ethnic minority students who have not been successful in science in traditional settings. This study provides preliminary support for the notion that learning in school gardens has the potential to promote STEM equity via the opportunity for students to experience different ways of learning science that are engaging and motivating, which in turn may promote students’ sense of science identity and science achievement. Participating in SciLG activities seemed to help diverse students not only engage more productively in science class, but also think of themselves as individuals who could be successful and valued as science contributors. Findings also lend support for the current motivational model, based on self-determination theory, as a means for capturing the “active ingredients” of SciLG activities. Together, the findings provide support for the SciLG program, and school gardens more broadly, as a milieu for promoting equity via science identity and achievement.
Table 1
Descriptive Statistics and Measurement Statistics

<table>
<thead>
<tr>
<th>Construct</th>
<th>Number of items</th>
<th>Crohnbach’s $\alpha$</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Independent Variable:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motivational Processes in the Garden (Spring)</td>
<td>31</td>
<td>.94</td>
<td>3.80</td>
<td>.76</td>
</tr>
<tr>
<td><strong>Subcomponents:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-system Perceptions</td>
<td>--</td>
<td>--</td>
<td>3.56</td>
<td>.84</td>
</tr>
<tr>
<td>Garden Engagement</td>
<td>--</td>
<td>--</td>
<td>3.90</td>
<td>.80</td>
</tr>
<tr>
<td>Garden Re-engagement</td>
<td>--</td>
<td>--</td>
<td>3.94</td>
<td>1.16</td>
</tr>
<tr>
<td><strong>Dependent Variables (Spring):</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science Engagement</td>
<td>12</td>
<td>.92</td>
<td>3.81</td>
<td>.92</td>
</tr>
<tr>
<td>Science Identity</td>
<td>9</td>
<td>.92</td>
<td>3.20</td>
<td>1.03</td>
</tr>
<tr>
<td>Science Learning</td>
<td>7</td>
<td>.92</td>
<td>3.83</td>
<td>1.03</td>
</tr>
<tr>
<td>Science Grades</td>
<td>n/a</td>
<td>n/a</td>
<td>3.07</td>
<td>.94</td>
</tr>
<tr>
<td><strong>Dependent Variables (Fall):</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science Engagement</td>
<td>12</td>
<td>.91</td>
<td>3.82</td>
<td>.82</td>
</tr>
<tr>
<td>Science Identity</td>
<td>9</td>
<td>.90</td>
<td>3.40</td>
<td>.89</td>
</tr>
<tr>
<td>Science Learning</td>
<td>7</td>
<td>.90</td>
<td>3.80</td>
<td>1.00</td>
</tr>
<tr>
<td>Science Grades</td>
<td>n/a</td>
<td>n/a</td>
<td>3.37</td>
<td>.99</td>
</tr>
</tbody>
</table>

Note. Total $n = 113$. Science grades ranged from 0 (“F”, lowest) to 4 (“A”, highest). All other constructs could range from 1 (“not at all true”) to 5 (“very true”). Negative items reverse-coded. All analyses conducted in MPlus 6.0, using Full-information Maximum Likelihood method for to estimate missing data.
Table 2
Inter-correlations and cross-time stabilities for study constructs.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Independent Variable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Spring Garden Experiences</td>
<td>--</td>
<td>.51</td>
<td>.48</td>
<td>.53</td>
<td>.22*</td>
</tr>
<tr>
<td>Dependent Variables</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Science Engagement</td>
<td>.71</td>
<td>.44</td>
<td>.60</td>
<td>.82</td>
<td>n.s.*</td>
</tr>
<tr>
<td>3. Science Identity</td>
<td>.59</td>
<td>.57</td>
<td>.36</td>
<td>.58</td>
<td>n.s.*</td>
</tr>
<tr>
<td>4. Science Learning</td>
<td>.72</td>
<td>.84</td>
<td>.64</td>
<td>.47</td>
<td>n.s.*</td>
</tr>
<tr>
<td>5. Science Grades</td>
<td>.31**</td>
<td>.24*</td>
<td>.31**</td>
<td>.24*</td>
<td>.55</td>
</tr>
</tbody>
</table>

Note. Total $n = 113$. Correlations for spring dependent variables are below the diagonal. Correlations for fall dependent variables are above the diagonal. Cross-time stabilities (fall-spring correlations) for each dependent variable are italicized on the diagonal. All coefficients significant at $p < .001$ unless indicated: ** $p < .01$, * $p < .05$, n.s. not significant. All analyses conducted in MPlus 6.0, using Full-information Maximum Likelihood method for to estimate missing data.
Table 3
Combined garden experiences as a predictor of concurrent and later science outcomes.

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Pairwise $n$</th>
<th>$\beta$</th>
<th>$SE$</th>
<th>$t$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Spring</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science Engagement</td>
<td>97</td>
<td>.65***</td>
<td>.06</td>
<td>10.05</td>
<td>.61</td>
</tr>
<tr>
<td>Science Identity</td>
<td>103</td>
<td>.59***</td>
<td>.08</td>
<td>7.76</td>
<td>.34</td>
</tr>
<tr>
<td>Science Learning</td>
<td>88</td>
<td>.70***</td>
<td>.06</td>
<td>10.98</td>
<td>.55</td>
</tr>
<tr>
<td>Science Grades</td>
<td>111</td>
<td>.29**</td>
<td>.10</td>
<td>2.75</td>
<td>.08</td>
</tr>
<tr>
<td><strong>Fall</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Science Engagement</td>
<td>82</td>
<td>.57***</td>
<td>.10</td>
<td>5.60</td>
<td>.26</td>
</tr>
<tr>
<td>Science Identity</td>
<td>90</td>
<td>.52***</td>
<td>.10</td>
<td>5.21</td>
<td>.21</td>
</tr>
<tr>
<td>Science Learning</td>
<td>68</td>
<td>.56***</td>
<td>.10</td>
<td>5.01</td>
<td>.26</td>
</tr>
<tr>
<td>Science Grades</td>
<td>101</td>
<td>.23*</td>
<td>.11</td>
<td>2.12</td>
<td>.04</td>
</tr>
</tbody>
</table>

Note. Total $n = 113$. *** $p < .001$, ** $p < .01$, * $p < .05$. Standardized regression coefficients shown from regressions conducted in MPlus 6.0, using FIML to estimate missing data. All analyses controlled for spring science teacher.
Figure legend/list of captions

*Figure 1*: Yearlong curriculum map, co-created with collaborating teachers and STEAM Teacher on Special Assignment outlining the primary learning gardens activities and alignment to classroom (district adopted) curriculum.

*Figure 2*. A depiction of motivational processes in the garden the support student motivational and science outcomes.
References


Stiles, J. (2016). *Partnership building as a broadening-participation strategy: Helping researchers and developers bridge the gaps in STEM education*. CADRE Brief. Community for
Advancing Discovery Research in Education. Waltham, MA: Education Development Center, Inc.


**Footnotes**

1. Science in the Learning Gardens is funded by the National Science Foundation Grant # XXXXXX. Any opinions, findings, and conclusions or recommendations are those of the authors and do not necessarily reflect the views of the National Science Foundation.

2. Delta State is a pseudonym assigned to the state where this project takes place, and refers to the partnering school district and university.
### APPENDIX A. NGSS Middle School Performance Expectations addressed via Gardens

<table>
<thead>
<tr>
<th>Disciplinary Core Ideas (Framework)</th>
<th>Disciplinary Component Ideas (Framework)</th>
<th>Middle School Performance Expectations (NGSS)</th>
<th>Potential Examples in Gardens</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NGSS Key:</strong> MS = Middle School (gr 6-8); LS = Life Science; ESS = Earth and Space Science; ETS = Engineering, Technology, &amp; Applications of Science</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Molecules to Organisms: Structures &amp; Processes</strong></td>
<td><strong>LS1-B</strong> Growth &amp; Development of Organisms</td>
<td><strong>MS-LS1-5.</strong> Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.</td>
<td>Investigate microclimates in the garden and the impact on growth of particular variety of plants; comparing fruit production of different strains/varieties of plants.</td>
</tr>
<tr>
<td></td>
<td><strong>LS1-C</strong> Organization for Matter and Energy Flow in Organisms</td>
<td><strong>MS-LS1-6.</strong> Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy into and out of organisms.</td>
<td>Explorations of food webs and matter flowing from air to plant to soil and back. Develop a molecular model of the complementary processes of plant photosynthesis and respiration.</td>
</tr>
<tr>
<td></td>
<td><strong>LS1-C</strong> Organization for Matter and Energy Flow in Organisms</td>
<td><strong>MS-LS1-7.</strong> Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.</td>
<td></td>
</tr>
<tr>
<td><strong>Ecosystems: Interactions, Energy, &amp; Dynamics</strong></td>
<td><strong>LS2.A</strong> Interdependent Relationships in Ecosystems</td>
<td><strong>MS-LS2-1.</strong> Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.</td>
<td>Studies of plant growth rates/biomass production in comparison to planting density; water quantities; compost and nutrients; and other factors.</td>
</tr>
<tr>
<td></td>
<td><strong>LS2.B</strong> Cycle of Matter and Energy Transfer in Ecosystems</td>
<td><strong>MS-LS2-2.</strong> Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.</td>
<td>Observe and explain different relationships in the garden (e.g., ladybug and aphid; legumes and nitrogen-fixing bacteria).</td>
</tr>
<tr>
<td></td>
<td><strong>LS2.B</strong> Cycle of Matter and Energy Transfer in Ecosystems</td>
<td><strong>MS-LS2-3.</strong> Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.</td>
<td>Construct visual models demonstrating carbon cycle, nitrogen cycle, and energy flow through the garden system.</td>
</tr>
<tr>
<td><strong>Earth’s Systems</strong></td>
<td><strong>ESS2.A</strong></td>
<td><strong>MS-ESS2-1.</strong> Develop a model to describe cycling of Earth’s materials and the flow of energy that drives this process.</td>
<td>Include abiotic factors in models of nutrient cycles.</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------</td>
<td>-------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------</td>
</tr>
<tr>
<td><strong>ESS3.C</strong></td>
<td><strong>Human Impacts on Earth Systems</strong></td>
<td><strong>MS-ESS3-3.</strong> Apply scientific principles to design a method to monitor and minimize a human impact on the environment. <strong>MS-ESS3-4.</strong> Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth’s systems.</td>
<td>Student groups identify aspects of food production impacting environment (e.g. water consumption, run-off, burning fossil fuel, etc.), articulate connections between population growth and consumption, then design strategies to minimize and/or mitigate negative impacts.</td>
</tr>
<tr>
<td><strong>Engineering Design</strong></td>
<td><strong>ETS1.A</strong></td>
<td><strong>MS-ETS1-1.</strong> Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.</td>
<td>Any number of student-identified problems and design-based solutions.</td>
</tr>
<tr>
<td></td>
<td><strong>ETS1.B</strong></td>
<td><strong>MS-ETS1-2.</strong> Evaluate competing design solutions using systematic process to determine how well they meet criteria and constraints of the problem. <strong>MS-ETS1-3.</strong> Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>ETS1.C</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>