# Garden TOOLS: Technology-rich agricultural engineering opportunities in outdoor learning spaces

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# Garden TOOLS: Engaging elementary students in technology-rich agricultural engineering projects in outdoor learning spaces

**Abstract**

As demand for food and energy continues to grow, so, too, does the importance of understanding agricultural systems and technologies. There is a need to prepare a science-literate citizenry capable of making informed decisions related to food, energy, and water in a world of rapid technological advancement. Outdoor learning spaces, such as school and community gardens, offer a compelling venue for K-12 students to engage in place-based, interdisciplinary STEM learning. While these spaces often support science instruction, technology and engineering learning opportunities are limited. To address this need, Garden TOOLS (Technology Opportunities in Outdoor Learning Spaces) engages upper elementary students (grades 3-5) in coding programmable BBC micro:bit microcontrollers as environmental sensors to facilitate exploration and technology-rich engineering projects in outdoor learning spaces. This program aims to cultivate learners' 21st-century skill development in preparation for a modernizing agricultural workforce and encourage learners to pursue career pathways related to agricultural engineering.

During Garden TOOLS programming, youth begin by using BBC micro:bits pre-coded as outdoor technology tools including a compass, counter, thermometer, light level meter, and soil moisture probe. Students then engage in basic tutorials to learn to code the BBC micro:bit using a block-based programming platform. A series of coding projects expand student understanding of circuits, sensors, and fundamental coding concepts. As youth gain computational thinking skills through programming experiences, they eventually apply their understanding to address student-identified garden challenges particular to their site. For example, students may program the BBC micro:bit to monitor soil moisture levels to establish an irrigation schedule.

Garden TOOLS has received an enthusiastic reception from participants including youth and formal and informal educators. Development efforts have focused on designing and piloting multiple instructional supports including standards-aligned curriculum materials suitable for use in formal or informal education settings and professional development training for after-school staff, pre-service and in-service elementary teachers, and Nebraska Extension personnel. So far, professional development training has been conducted with 93 informal educators and 178 formal educators.

## Introduction

To address growing global demand for food, energy, and water, modern society has become increasingly reliant on solutions that exist at the intersection of science, technology, engineering, and mathematics (STEM). Given the importance of STEM-informed solutions, there is a need to prepare a STEM-literate citizenry capable of making informed decisions related to food, energy, and water in a world of rapid technological advancement.

To address the need for STEM-literate learners, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* [1] has outlined key science and engineering competencies that all students should attain by the end of 12$^{th}$ grade. The *Next Generation Science Standards* (NGSS) were developed based on the *Framework* and unlike the prior National Science Education Standards [2], engineering design has been elevated "to the same level with scientific inquiry" in the NGSS [3, p. 437]. With 44 states (representing 71% of all U.S. students) adopting NGSS or similar Framework-based standards [4], this shift offers an unprecedented opportunity for students to learn engineering in K-12 classrooms.

Despite support for increased integration of engineering into pre-college instruction, presentation of engineering content in both formal and informal education settings is still limited. The 2018 National Survey of Science and Mathematics Education (NSSME+) indicates that a majority of teachers at the elementary (64%), middle school (61%), and high school (70%) grade levels report rarely, if ever, incorporating engineering into science instruction [5]. In addition, research has highlighted that opportunities to engage with technology and engineering in afterschool programs are limited when compared to the availability of programming in the other disciplines encompassed by STEM (Figure 1, Afterschool Alliance, 2016).

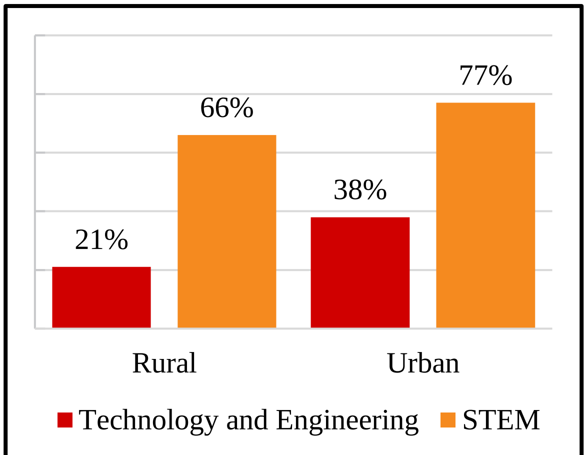

Figure 1. Differences in Afterschool Learning Experiences by Locale. Adapted from Afterschool Alliance, 2016.

Research would suggest that a lack of educator confidence and training may limit teachers' willingness to incorporate engineering into K-12 science instruction. Findings from the 2013 NSSME+ indicated that only 1% of elementary teachers had previously completed a college course in engineering and only 4% felt very well prepared to teach engineering [7]. Similarly, empirical findings have demonstrated elementary teachers' lack of self-efficacy related to teaching engineering [8]. In addition, at secondary grade levels, teachers' engineering training is not much better with 10-14% of middle school teachers and 6-8% of high school teachers feeling very well prepared to teach engineering [5]. Given K-12 teachers' limited engineering background and lack of self-efficacy, it is essential to provide both formal and informal educators with high-quality instructional supports and professional development opportunities to ensure successful integration of engineering into future science instruction.

All engineering fields offer valuable contributions to K-12 engineering education; however, agriculture-related engineering fields may be able to leverage unique strengths and benefits of agriculture-based experiential learning to provide K-12 students with engineering experiences that other engineering fields cannot. As educators seek to build on students' prior knowledge and experiences, agriculture provides a context that is both relatable and accessible to students in a variety of education settings. Germinating seeds and cultivating plants offer easy and affordable learning experiences for students of all ages and abilities. Plants can be cultivated in the classroom or in school gardens which are growing in popularity with the number of garden programs in U.S. public elementary schools doubling from 2006 to 2013 [9]. While growing plants does not require digital technologies, common garden tasks such as tracking weather, managing pests, and scheduling irrigation offer opportunities to design and implement technology-rich solutions to address authentic problems rather than contrived "school science" challenges. As students learn to apply their STEM knowledge and skills to grow their own fruits, vegetables, herbs, seeds, and flowers, they take on role of "creator" rather than simply "consumer". It is with this shift that students can engage in a transformative learning experience whereby STEM knowledge and skills are developed during the course of meaningful agricultural pursuits relevant to their own lives and may begin to envision themselves as future agriculture professionals [10]–[12].

**Program Objectives**

In order to leverage the transformative power of agriculture-based experiential learning in outdoor growing spaces and increase elementary students' access to high-quality agricultural technology and engineering education, Garden TOOLS (Technology Opportunities in Outdoor Learning Spaces) was created.

The objectives of Garden TOOLS are to:

- Create a standards-driven, agricultural technology and engineering curriculum and associated resources to empower youth in grades 3-5 to improve outdoor learning spaces with data-informed decision making and technology-rich engineering projects.
- Implement professional development trainings to equip educators to teach computational thinking and decision-making skills through the application of agricultural technology tools in outdoor learning spaces.

**Curriculum Development**

The Garden TOOLS curriculum was developed using a backwards design approach [13] to facilitate computational thinking and decision making in school and community garden spaces. It employs research-based recommendations to support student computational thinking skill development. Recommended practices include 1) supporting youth engagement with a computationally rich environment where abstract elements are made concrete through direct manipulation within a block-based coding platform and 2) facilitating programming experiences guided by the Use-Modify-Create learning progression which scaffolds student learning as they transition from the role of technology user to technology creator [14].

The curriculum was designed to support students in programming and using the BBC micro:bit, an affordable micro-computing device costing less than US$20.00 (Figure 2) to enhance the decision-making process and engineer technology-rich solutions. Released in 2016, the BBC micro:bit is an innovative device that is compatible with multiple computing platforms including Mac, PC, Chromebook, and Linux as well as iOS and Android. It can be coded in numerous programming languages including javascript and Python. The BBC micro:bit features a 25-LED display, on-board sensors including light, temperature, compass and accelerometer, 2 programmable buttons, USB, radio, and Bluetooth connectivity, and edge connector pins for accessories. For the purposes of the Garden TOOLS curriculum, the BBC micro:bit is coded to measure various sensory inputs (i.e. light, temperature, moisture, acceleration, and motion) via a browser-based drag-and-drop javascript coding editor, Microsoft MakeCode (http://makecode.microbit.org). Once programmed, the BBC micro:bit can be powered via battery pack (without computer interaction) allowing users to collect data both indoors and outdoors. The BBC micro:bit is a powerful and flexible technology tool that is suitable for use with students in grades three and up.

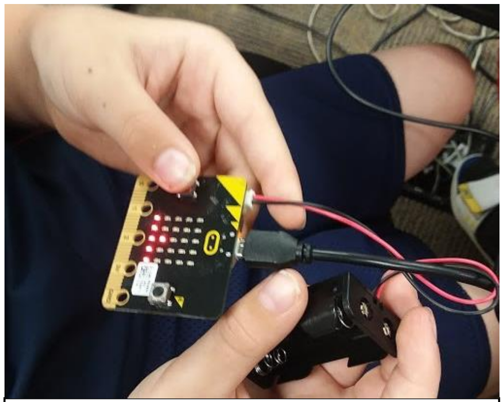

Figure 2. Student programming BBC micro:bit to collect data from an outdoor learning space.

The standards-aligned Garden TOOLS curriculum includes nine lessons requiring an estimated 15 hours to complete. Student learning outcomes include the ability to:

- Program a BBC micro:bit to collect data in an outdoor learning space.
- Make informed management decisions based on assessment and analysis of data.
- Integrate the BBC micro:bit and other suitable technologies into engineering design solutions to address student-identified garden challenges.

To achieve these learning outcomes, the Garden TOOLS curriculum uses a project-based learning approach [15] in which students are challenged with unstructured, authentic problems when creating and managing a productive, safe, and appealing garden space. Youth engage in sustained inquiry throughout the experience to ask questions, gather information and resources, and apply their understanding and skills to improve the garden space through data-informed decision making and technology-rich design solutions. Potential design solutions may include a device for counting garden visitors, monitoring and maintaining water quality, automating irrigation, motion-activated pest control, and selecting plants adapted to local conditions.

As part of the inquiry process in the project-based learning approach, youth begin by using BBC micro:bits pre-coded as outdoor technology tools including a compass, counter, thermometer, light level meter, and soil moisture probe. Students then engage in basic tutorials to learn to code the BBC micro:bit using the block-based programming platform. A series of coding projects expand student understanding of circuits, sensors, and fundamental coding concepts.

Youth code the BBC micro:bit to serve as various age-appropriate and accessible agricultural technology sensors to monitor environmental conditions. As youth gain computational thinking skills through programming experiences they begin to apply their understanding to address garden challenges particular to their site. For example, students may program the BBC micro:bit to monitor soil moisture levels to establish an irrigation schedule. Students will apply their computational knowledge and skills to prototype technology-integrated solutions to garden challenges they have identified.

Initial curriculum materials were piloted in 2019 with three 21st Century Community Learning Center (21st CCLC) afterschool programs, where ethnic minorities and low-income youth tend to be overrepresented [16]. Following implementation, the curriculum was refined and expanded to include engineering design challenges and support resources including how-to coding guides, video-based coding tutorials, and a website for digital access to Garden TOOLS resources.

**Professional Development**

While the format and length of professional development (PD) trainings were variable, all trainings addressed one or more of the following objectives:

- Challenge the perception that technology does not belong in outdoor learning spaces
- Gain competencies in using and programming the BBC micro:bit to support exploration, decision-making, and engineering in outdoor spaces
- Support development of students' computational thinking and decision-making skills using the Garden TOOLS curriculum and associated resources

Initial PD trainings requiring 8-10 hours of contact time were developed for use with informal educators using a blended learning approach in which online learning opportunities were combined with traditional face-to-face interactions. First, an online short course was created to introduce participants to computational thinking and the function and features of the BBC micro:bit via Google Classroom. The goal of the short course was to act as a primer giving participants a chance to become familiar with the technology and 21st century learning prior to participating in face-to-face training sessions. During follow-up face-to-face sessions, we introduced participants to the Garden TOOLS curriculum through experiential learning with a focus on peer-to-peer collaboration on computational thinking exercises, engineering design challenges, and programming, exploration, and environmental data collection using the BBC micro:bit in an outdoor space.

Initial PD trainings were piloted with informal educators including 21st CCLC afterschool program staff and county-based Nebraska Extension educators at three participant-selected sites during summer 2019. During implementation, it became apparent that barriers related to time and staff interest and availability made engagement with an 8-10-hour PD training over multiple sessions especially challenging.

Around the same time, partnership opportunities arose with the University of Nebraska–Lincoln College of Education and Human Sciences (CEHS) allowing for piloting of shortened, in-person PD sessions with pre-service and in-service elementary teachers. These abbreviated sessions did not introduce the Garden TOOLS curriculum, but instead focused on providing participants with a limited programming and exploration experience in which participants coded and used the BBC micro:bit to explore environmental conditions in an outdoor setting followed by a purposeful discussion on sense-making practices and uncovering students' ideas.

**Impact**

During the two-year development and implementation of the Garden TOOLS program, we have designed and piloted curriculum materials and a variety of professional development (PD) experiences for both formal and informal educators (Table 1).

Table 1. Summary Garden TOOLS PD training sessions

| **Audience** | **Length** | **Format** | **Context and Content** | **# of Participants** |
|---|---|---|---|---|
| Informal | 1 hour | In-person | Single session taught to attendees at statewide afterschool conference. Content focused on coding micro:bits as soil moisture sensors to gather data in garden spaces. | 15 |
| Informal | 8-10 hours | Online + In-person | Online short course and two sessions taught to afterschool staff and Extension educators. Content focused on computational thinking, engineering design, coding and use of micro:bits to gather data and explore garden spaces. | 8 |
| Informal | 2 hours | In-person | Single session taught as part of an Outdoor Learning Series in cooperation with community partners and school district leadership provided to afterschool staff from three school sites. Content focused on coding and using the BBC micro:bit to explore environmental conditions, introducing sense-making practices, and uncovering students' ideas. | 5 |
| Informal | 1 hour | In-person | Single session taught at statewide afterschool conference. Content focused on family engagement and using micro:bits in garden spaces. | 65 |
| Formal (Elementary Pre-service) | 2 hours | In-person | Single session taught during an integrated STEM methods course block. Two sessions taught in Spring 2019. Four sessions taught in Fall 2019. Content focused on coding and using the BBC micro:bit to explore environmental conditions, introducing sense-making practices, and uncovering students' ideas. | 164 |
| Formal (Elementary In-service) | 1.5 hours | In-person | Single session taught to cohort of K-8 rural STEM teachers during a Technology for Teaching STEM course as part of a NSF Robert Noyce Teacher Scholarship grant. Content focused on coding and using the BBC micro:bit to explore environmental conditions, introducing sense-making practices, and uncovering students' ideas. | 14 |

One of the greatest strengths of Garden TOOLS has been the ability to meet the diverse needs and interests of formal and informal educators working within a variety of situational constraints (i.e. limited time, staff availability, access to outdoor spaces, etc.). The pilot PD trainings conducted with many different audiences have provided a wealth of qualitative data in the form of both participants feedback and facilitator reflection that has been used to identify successes and challenges to the Garden TOOLS program and can be used to guide future iterations of PD trainings.

Overall, Garden TOOLS PD trainings have received an enthusiastic response from participants with both formal and informal educators expressing increased confidence not only in their coding skills, but also in teaching STEM subjects. Pre-service elementary teachers provided the following feedback after experiencing the PD training:

- “Prior to using the micro:bits I had only done a little bit of coding, but now I have more experience and feel more confident than I did before.”
- “This tool [BBC micro:bit] will not only help my students improve in these [STEM] subjects, but also help me to feel more comfortable and confident in teaching these subjects.”
- “I see myself using the micro:bit as a tool to enhance and motivate my students learning in difficult subjects or subjects I am struggling to teach.”

Perhaps even more encouraging is the fact that several educators saw connections between facilitating technology-rich learning experiences and the influence this might have on students’ STEM identity and career pathways:

- “A quote from the [BBC micro:bit] website stated it best, “Micro:bits prepare our students for the future jobs that do not exist yet.” Being truly impressed with this new piece of technology and its possibilities, I placed an order for one of my own. It’s never too late to start coding and my future students will benefit in the long run.”
- “The micro-bit is a great tool for us to use, especially since we are living in the age of technology. So that students are successful in their future professions, teaching them about these devices as well as letting students use them is crucial to their STEM identities and the career paths they will take.”

While educators appeared to make great strides toward becoming more comfortable and confident in integrating technology into their future classroom or afterschool program, participant feedback did not indicate increased confidence in using the BBC micro:bit to support engineering technology-rich design solutions to school garden challenges.

Many factors may be responsible for educators’ lack of increased engineering education confidence after participating in a Garden TOOLS PD training. First, it is likely that the Garden TOOLS program may be asking “too much, too soon” from participants. The Garden TOOLS PD requires participants to develop knowledge and skills in several unfamiliar content areas at once and this undoubtedly requires more time than our current shortened PD experiences can support. In reflecting on educators’ learning progression during the PD, they first become familiar with the BBC micro:bit as a new technology tool and gain coding skills. It is only then that they learn about engineering design and begin to practice integrating the BBC micro:bit into design solutions. It is possible that with additional PD training, educators would gain the necessary engineering knowledge and skills and in turn, grow more confident in facilitating engineering education experiences that include technology. Another possible reason for the lack of educator engagement in technology-rich design projects is that contextual factors are acting as barriers. In some cases, informal educators described previously facilitating successful engineering experiences in their afterschool programs, but they pointed to situational constraints such as limited time or staff availability as key challenges to incorporating garden-based engineering projects involving the BBC micro:bit in the future.

Despite the overwhelmingly positive response to the Garden TOOLS program, we have learned several important lessons based on facilitator experiences and participant feedback. Our key takeaways include:

**Start small to avoid overwhelming your audience**.

All Garden TOOLS PD trainings required that participants engage with STEM content and an unfamiliar technology tool (i.e. the BBC micro:bit), both of which were viewed with apprehension by most participants. Based on facilitator experiences, it may be asking too much of educators to learn to code and use an unfamiliar technology tool while also introducing engineering design, computational thinking, and engaging students in outdoor learning. Best practices for creating and implementing effective professional development for educators call for programs of sustained length to have an impact on teacher practice. However, in our experience, long-term engagement with multiple PD training sessions was difficult to schedule, did not guarantee educator buy-in, and was not met with as much enthusiasm as short-term PD experiences.

While the program offers a potentially transformative experience allowing for integration of technology and engineering into outdoor learning spaces, it can be easy to overwhelm educators who view this approach as "too much, too soon". Fortunately, in-person PD sessions of less than two hours appeared to offer a more accessible and rewarding experience for both informal and formal educators. This positive experience left participants wanting more, but not feeling overwhelmed. Moving forward, we will look for opportunities to offer shorter PD trainings (e.g. Beginner, Intermediate, and Advanced) that can build on one another into a more comprehensive PD experience.

**Face-to-face learning opportunities work best when getting started**.

While research on adult learners indicates a preference for self-guided learning opportunities, limited participant feedback in the blended (online and in-person) PD training indicates that informal educators did not use the online short course prior to the in-person PD workshops. It is possible that a lack of time or compensation for taking part in the PD training may have negatively impacted educators' decision to fully participate, but it is also possible that the lack of participants' familiarity with the content and lack of face-to-face social interaction made the online delivery method less appealing.

In contrast, in-person PD trainings proved to offer many effective learning opportunities. This format allowed for workshop facilitators to provide direct instruction, answer questions, and troubleshoot technology issues as they arose it also supported a high-level of experiential and social learning through partner programming of the BBC micro:bit. In the future, we may focus our efforts on delivering PD via in-person workshops or offer an online short course after (rather than before) the in-person training.

**During training, encourage participants to work with a partner.**

Based on extensive participant feedback, many formal and informal educators initially felt apprehensive about coding, specifically, and technology, more generally. Fortunately, participant feedback indicated that educators gained confidence by completing a brief tutorial and successfully coding the BBC micro:bit as a light level, temperature, or soil moisture sensor with a partner.

Learning unfamiliar content or developing a new skill such as coding can make participants feel vulnerable, however, by working with a partner, learning can become more fun and less scary. We noticed that when participants programmed the BBC micro:bit with a partner, they tackled challenges more confidently and celebrated successes together. It is notable that in our trainings, initial coding experiences did not need to be time intensive to impact participant confidence. Providing a 30-minute coding session with sufficient facilitator support provided ample time for participants to build confidence in their ability to code using a block-based coding platform.

## Future Directions

We plan to focus our future efforts on enhancing sustainability and evaluation of the Garden TOOLS program.

To address the issue of long-term sustainability of the program, we are continuing to work with University of Nebraska–Lincoln College of Education and Human Sciences (CEHS) faculty to integrate a revised version of the Garden TOOLS PD training into the science methods courses required for pre-service elementary teachers. As part of this partnership, grant funds provided by CEHS have been used to purchase BBC micro:bits and assorted accessories (e.g. alligator clips, nails, etc.) that are assembled into classroom kits which can be checked-out by pre-service teachers for use during their student teaching experience.

In addition, steps are being taken to evaluate the effectiveness of the Garden TOOLS program in increasing formal and informal educators' technology and engineering competency and confidence. To formally assess the impact of the Garden TOOLS PD training on informal educators, qualitative data including participant survey feedback and facilitator reflections will be used to inform the selection or creation of future evaluation tools. In addition, CEHS research collaborators are in the in the process of evaluating the Garden TOOLS PD training as part of a larger effort to assess the impact of an integrated STEM teaching methods course block on pre-service elementary teachers' science teaching self-efficacy.

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- Elementary pre-service teacher participants
- Rural STEM in-service teacher participants

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