The Go-To Guide for

ENGINEERING CURRICULA PreK–5

Choosing and Using the Best Instructional Materials for Your Students

EDITED BY

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Proofreader: Rae Ann Goodwin
Indexer: Michael Ferreira
Cover Designer: Gail Buschman

Printed in the United States of America.

A catalog record of this book is available from the Library of Congress.

ISBN 978-1-4833-0736-7

This book is printed on acid-free paper.

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Engineering for Everyone

4-H's Junk Drawer Robotics Curriculum

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Are you wondering how to teach robotics? Are you looking for an inexpensive and fun engineering education curriculum for upper elementary and middle school youth? Then, 4-H's Junk Drawer Robotics (JDR) is for you. Using common household items such as paper clips, brass brads, toy motors, craft sticks, batteries, aluminum foil, binder clips, and many others, JDR engages youth in science inquiry, the engineering design process, and technology creation and building. Activities emphasize *design* as a pedagogical strategy, as educators engage youth, through design, with science, technology, engineering, and mathematics (STEM). This approach helps prepare young people to be creative problem solvers while developing dispositions as designers, which will serve them well in our digital society.

The key elements of JDR are scientific and engineering practices; facilitator instruction framed in the experiential learning cycle; and small-group collaborative learning. It also offers excellent opportunities for cross-age facilitation (teenagers-as-teachers). Published by National 4-H Council in 2011 as part of the 4-H Science Initiative, JDR is strengthening and reaffirming 4-H's legacy for high-quality science education in out-of-school time.

In Junk Drawer Robotics, teen mentors work with children, using hand tools to design and build robots from simple materials.

Image by R. Mahacek, courtesy of 4H National Council.

Educational robotics is emerging as a promising method to engage youth in STEM education. Educational robotics promotes an interdisciplinary approach, truly integrating STEM education while improving motivation for learning. In addition, educational robotics helps strengthen collaboration and fosters 21st century skills (Eguchi, 2012).

To download a sample activity and learn how to obtain all of the JDR materials, visit www.4-H.org/curriculum/robotics.

Big Ideas and Science Themes in Junk Drawer Robotics

The JDR curriculum consists of three levels in the form of facilitator guides. The first level is *Give Robots a Hand*, which focuses on robot arms and grippers. The second level is *Robots on the Move*, where youth learn about robot movement. The third level is *Mechatronics*, which emphasizes mechanical, electronic, and feedback systems and how these systems work together. A youth notebook has sections for each level and encourages youth to think like scientists and engineers, by recording data and ideas, drawing designs, and reflecting on their experiences. The notebook also provides specific information for the challenge activities. Following is a summary of the big ideas and science themes in each of the three levels.

Give Robots a Hand

Arms are flexible with joints—shoulders, elbows, and wrists—that allow us to place our arms in many positions. The hand with its fingers and thumb can grab, hold, and pick

Each of the Three Levels Includes a Facilitator Guide

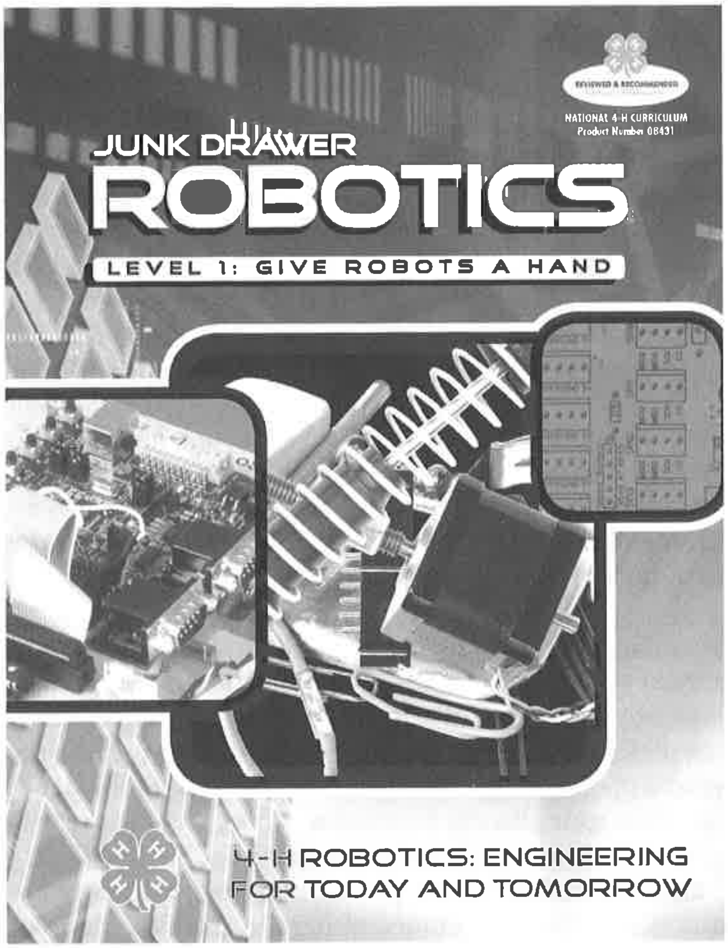

Image courtesy of 4-H National Council.

up items. Robot arms allow robots to grab, lift, move, or position items. Activities in *Give Robots a Hand* involve exploring the design and function of robotic arms, hands, and grippers and building a robotic arm that really moves!

The underlying science concepts in *Give Robots a Hand* include the crosscutting concept of structure and function. That is, the functioning of natural and built systems alike depends on the shapes and relationships of certain key parts as well as on the properties of the materials from which they are made. Robot designers often use simple machines (such as levers, gears, or wheels and axles) as tools to enable their robots to have certain functions. The fundamental ideas of simple machines can be thought of as special cases of structure and function. The activities in *Give Robots a Hand* also enable youth to explore the core physical science ideas that different materials have different properties, which make them better for some applications than others, and qualitative understanding of forces and interactions, including the idea of leverage.

Engineering and technology concepts in *Give Robots a Hand* include the core ideas of engineering at the upper elementary level—defining the problem to be solved, generating and comparing multiple solutions, and planning and carrying out fair tests (controlled experiments) to improve the design. Through their activities, youth learn that engineering design is a purposeful process of generating and evaluating ideas to develop and implement the best possible solution to a given problem.

Perhaps most important, by bringing the ideas of science and engineering together, youth learn that understanding physical science and mathematics concepts is necessary in making engineering design decisions. The enduring understandings about robots that youth develop are that the physical design (form) of a robot is based on its intended function, and it is often necessary to choose certain materials and design elements (e.g., pneumatics, levers) or otherwise constrain the design in order to achieve the goal. The robot's structure, components, and programming determine its potential behaviors and enable its function.

Robots on the Move

Mobility allows robots to complete tasks in locations and situations impossible for humans. Mobile robots can be used on land, in the air, on the surface, or underwater. A mobile robot can be controlled remotely using a cord or tether, radio control, or with programmed instructions. In *Robots on the Move*, youth design and build machines that roll, slide, draw, or move underwater and explore robot mobility—movement, power transfer, and locomotion.

The underlying science concepts in these activities include friction (energy and forces), basic electrical power and motors, gears systems, and buoyancy. Buoyancy is the force that causes an object to float in a fluid. An underwater remotely operated vehicle needs to be near neutral buoyancy so it can operate under water. Friction can slow down or limit the movement of objects, but friction is also a useful tool when we need traction or gripping power. A drive train directs the motion, speed, and direction of the movements from a motor. Gears, levers, and cams are components of a drive train.

Engineering and technology concepts emphasized in *Robots on the Move* include the role of constraints and the importance of iteration, which involves multiple trials to improve a design. As in the other units, understanding of underlying physical science and mathematics concepts is necessary in making engineering design decisions.

The crosscutting concept of cause-and-effect spans both science and engineering. In science the goal is to explain a phenomenon, usually by discovering its cause. In engineering the goal is to design a system to cause a desired effect, so cause-and-effect relationships are as much a part of engineering as of science. Indeed, the process of design is a good place to help youth begin to think in terms of cause-and-effect, because they must understand the underlying causal relationships in order to devise and explain a design that can achieve a specified objective.

Mechatronics

Robots are designed to perform a specific job better than it could be done by a person or another machine. They also provide an excellent example of the synergy that occurs when mechanical, electronic, and feedback systems are merged. Essential components include sensors that enable a robot to detect phenomena in the world around them, control systems that enable them to interpret the inputs they receive, and mechanical and electronic systems that enable them to carry out tasks. In this unit, youth explore sensors, computer science concepts, build circuits, and design their own robot.

The underlying science concepts include electronic circuits, sensing, and the binary number system. Youth have hands-on experiences, without computers, to learn important concepts in computer science, including programming that allows humans to control robot behavior. They learn how to use basic logic elements to predict outcomes and the essential ideas of Boolean logic, which forms the basis of all modern digital electronics. They also create flowcharts to help them design and clarify instructions for their robots.

Engineering and technology concepts guide the young peoples' applications of their growing knowledge of electronics and computers to compare different design ideas, to integrate the different systems into a working robot, and to troubleshoot their inventions in order to identify and repair failure points.

The crosscutting concept that spans science and engineering most appropriate for this unit is systems and system models. Just as scientists create simplified models to study complex interacting systems in the natural world, engineers also isolate a single system and construct a simplified model of it. This is especially important when designing a robot, which involves multiple complex interacting systems.

Flow of Activities

Each of the three books, or levels, contains three to five modules. Within a module there is a sequencing of activities in three stages: To Learn, To Do, and To Make. In this sequence, youth learn like scientists (To Learn), design like engineers (To Do), and build like technicians (To Make).

To Learn (Science Inquiry). These activities emphasize exploration and form the foundation upon which youth build conceptual understanding. Youth learn the underlying scientific concept through activities that contain minimal guidance or expectations of accomplishments. Through intentional debriefing, educators pose open-ended questions to help youth reflect individually and in groups.

To Do (Engineering Design). The design activity takes place after exploration of the scientific concepts in "To Learn" activities. Youth are presented with a design problem and work together to design and plan a solution. This phase promotes the engineering design concepts of problem identification, framing, and solving. Deeper learning happens because youth build upon the knowledge gained in the exploration phase and intellectually create a design without using the physical objects.

To Make (Technology Creation, Testing, and Rebuilding). After the design activity, youth build, construct, and test their solution. This stage often involves modifications to the original design. During this time, youth solidify their understanding of the scientific concepts as they enact a solution, build a prototype, and test the design. Through facilitated debriefing by the educator, youth compare their product to those constructed by the other groups.

This process allows youth to explore new knowledge using science inquiry, then build upon those budding concepts by applying them in designing, creating, and refining technologies. The curriculum captures the synergy between science, engineering, and technology by sequencing learning in such a way to allow each focus area to be addressed separately, yet highlights and reinforces the interconnections. In this manner, the curriculum supports the core idea that science, engineering, and technology continuously interact and move each other forward.

Get Things Rolling

Following is a vignette of a single activity from the first module of Level 2 Robots on the Move.

In order to extend the longevity of a robot's mechanical parts, it must be properly designed to minimize friction and reduce energy consumption. Get Things Rolling is a sequence of activities that help youth begin to understand friction, how friction depends on the properties of materials, and the application of these ideas in robotics.

Slip N Slide (To Learn—Science Inquiry). Youth begin by investigating how a box of paper clips slides down an angled cardboard ramp. The ramp consists of a number of surfaces with varying degrees of resistance. For example, some surfaces might be sandpaper, packaging tape, duct tape, and aluminum tape. Youth are asked to record the degree of incline required to overcome static friction—the angle at which the box begins to slide—for the various ramp surfaces.

Rolling Along (To Learn—Science Inquiry). Next, youth are challenged to modify their box of paper clips to reduce friction. Some youth may find that covering their box of paper clips with packaging tape works while others may add wheels (perhaps using paper clips and straws) so the box rolls down the ramp rather than slide.

The Clipmobile Challenge (To Do-Engineering Design; and To Make—Technology Creation, Testing, and Rebuilding). After the above investigations, youth are divided into teams and challenged to design and build a clipmobile—a vehicle that can overcome friction and travel down the ramp and continue traveling. The challenge incorporates the engineering aspect of "constraints" as each team has a certain amount of pretend money they can use to purchase parts for their clipmobile from the "Junk Drawer Supply Company." The company stocks parts, including craft sticks, paper clips, brass paper brads, binder clips, straws (drinking and coffee), rubber bands, wheels, and wood skewers. Free services include the use tools, such as pliers, wire cutters, saws, and hand-operated drills or punches. The first component of the activity (To Do) asks youth to work together to design a clipmobile and plan the type and number of parts their design

Cardboard Ramp With Various Surfaces (Left) and Box of Paper Clips (Right) Ready to Roll Down the Ramp

a. b.

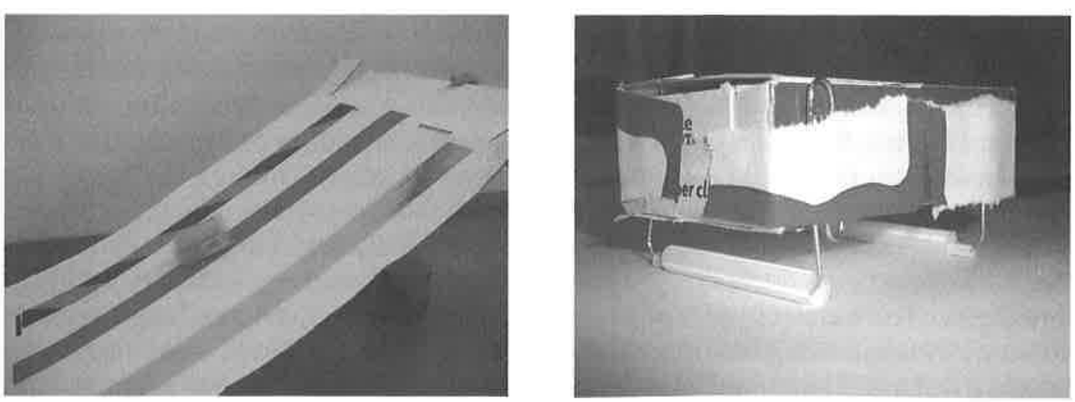

Image by R. Mahacek, courtesy of 4H National Council.

will require. The second component (To Make) invites youth to build their clipmobile, test it on the ramp, and rebuild it if necessary to improve performance.

Teams evaluate themselves on a number of factors, including weight capacity of their clipmobile, performance, and the cost effectiveness of their budget. Teams demonstrate their vehicle to the class along with an inventory sheet of parts and their budget. Even with the best performance (going the longest distance off the ramp), a team will not necessarily have the most effective clipmobile if they purchased a large number of parts. In the end, youth learn that the engineering design process often includes real-life constraints that impact the engineering design process. To conclude the activity, the educator helps youth reflect on their experience through sharing, processing, and generalizing. This includes posing questions for youth to reflect on individually and in groups.

Visit the 4-H Robotics page to download this sample activity: www.4-H.org/curriculum/robotics.

Junk Drawer Robotics Promotes Creativity and Problem Solving

JDR engages youth in learning science and engineering through the practices of science inquiry and engineering design. Our design-based learning approach fosters problem solving and critical thinking (Lee & Breitenberg, 2010), strengthens creativity (Doppelt, 2009), and is consistent with how youth naturally learn (Blumenfeld et al., 1991). Design-based learning is a special case of project-based learning, which helps youth develop skills in planning and construction, and testing, with frequent opportunities for reflection and metacognition. The end result is the creation of shareable artifacts that serve as external representations of the youths' growing knowledge and sense of accomplishment. An important part of the learning process involves reflection on the design and construction processes and the on the final artifact itself.

Elements of the Junk Drawer Robotics Curriculum

Focus on Scientific and Engineering Practices. The curriculum emphasizes scientific and engineering practices (although the curriculum uses the term "science processes" and "science, engineering, and technology abilities"). Through hands-on activities, youth identify, frame, and explore concepts and then apply their learning through design and construction. This approach helps youth develop critical thinking skills and scaffolds their ability to apply their knowledge to problem-solving activities. When extended over time, youth work toward advanced concepts. Engineering practices are enhanced when incorporated with communications, teamwork, and hands-on activities.

Hands-On Learning Through the Experiential Learning Cycle. The experiential learning cycle, which nurtures natural curiosity, contains three steps: (1) experiencing; (2) sharing and processing; and (3) generalizing and applying (e.g., Kolb, 1984). Each activity begins with an experience. After the experience, presenters help youth reflect on the activity by encouraging sharing and processing with open-ended questions. To complete the learning cycle, each activity contains a generalizing and applying section to help youth connect concepts to broader robotic concepts and to the real world. In addition, each module, which consists of several activities, also follows the learning cycle. Youth begin by exploring basic science concepts and processes, then apply what they have learned through designing and building activities.

Small-Group Collaborative Learning. Youth participants learn from each other by working in pairs or small groups. The opportunity for youth to collaborate, share, and work with each other promotes collaborative learning while also enhancing skills in teamwork, communication, and group decision making.

Engaging Teens as Mentors for Younger Children. JDR encourages teenagers to facilitate activities with younger youth. Older teens interact with younger learners and work together to explore the big ideas identified in each module. Allowing teens to teach younger youth has been shown to provide benefits for both the teens and younger participants (Lee & Murdock, 2001). Suggestions for helping teens become effective mentors can be found in the online facilitator guide.

Junk Drawer Robotics and the NGSS

Although JDR was developed before release of the Framework (NRC, 2012) and the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), it can be used to support all three dimensions of the NGSS.

Practices of Science and Engineering. JDR engages youth in all eight practices of science and engineering in the following ways:

1. **Asking questions (for science) and defining problems (for engineering).** Each three-part cycle begins with a scientific question. For example, in the above example,

The Experiential Learning Cycle

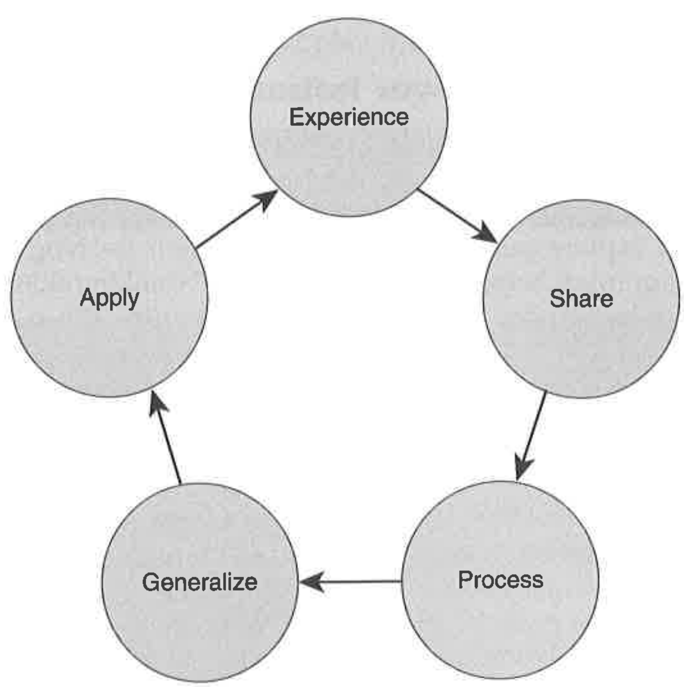

Image courtesy of 4-H National Council.

youth investigate how friction affects motion. Then, in the design challenges youth often need to clarify and define the problems that they are attempting to solve.

2. **Developing and using models.** Every level involves youth in developing and using models of robots, which are in turn models of various parts of the human body. For example, in the first-level activities, youth must model the ways that people use their hands and arms in various ways.
3. **Planning and carrying out investigations.** Youth control variables as they conduct investigations to answer scientific questions. This is evident in the friction activity above. Later, as they develop robotic systems, they carry out further investigations as engineers to see if their designs work in practice.
4. **Analyzing and interpreting data.** In both their science and engineering activities, youth collect and analyze data, aided by their youth notebook, which they then apply to their designs.
5. **Using mathematics and computational thinking.** Measurement is needed in each of the levels, while computational thinking is introduced primarily in level three: *Mechatronics.*
6. **Constructing explanations (for science) and designing solutions (for engineering).** As youth complete their inquiry activities, they are asked to reflect on what they've learned and explain concepts such as friction. Their designs and completed robots are their design solutions.
7. **Engaging in argument from evidence.** Facilitator guides urge educators to engage youth in frequent reflection and discussion, during which the youth discuss their current thinking based on their experiences. The friendly competitions facilitate arguments about the best solutions and provide evidence in support of some ideas over others.
8. **Obtaining, evaluating, and communicating information.** Youth are encouraged to go beyond these activities to learn more about robotics and related ideas from a variety of sources, aided by the Career Connections in the facilitator guides. Youth communicate their ideas through writing and drawing in their robotics notebook. They practice communicating their ideas verbally in the reflections and presentations at the end of each module.

Crosscutting Concepts. Each of the three levels emphasizes one of the seven crosscutting concepts from the Framework and NGSS:

Structure and Function is a key idea in *Give Robots a Hand,* since youth must consider both the materials and shape of the parts that they use to construct a robotic hand such that it functions as intended.

Cause and Effect is an essential idea in *Robots on the Move.* The investigations conducted by youth lead to causal principles, which they then apply in their design efforts to create effects that they want.

Systems and System Models is a perfect fit for *Mechatronics,* in which youth synthesize the mechanical and electronic systems to design and create robots of their own design.

Core Ideas. JDR provides opportunities for youth to learn about core ideas at the fourth and fifth grade levels in both the physical sciences and engineering design. For example, consider the following performance expectations from the NGSS (the first number indicates grade level):

4-PS3–2. Make observations to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents. (Transfer of energy from place to place is woven into each level.)

4-PS3–4. Apply scientific ideas to design, test, and refine a device that converts energy from one form to another. (Conversion of energy from one form to another—from electrical energy to kinetic energy—is emphasized in all levels.)

4-PS4–3. Generate and compare multiple solutions that use patterns to transfer information. (In the third level, youth learn to use patterns to simulate the process of programming to give instructions to their robots.)

4-LS1–2. Use a model to describe that animals receive different types of information through their senses, process the information in their brain, and respond to the information in different ways. (Robots provide an excellent model for using nature, to inspire engineering designs, for example, how animals sense their environment, interprets the information, and responds.)

5-PS1–3. Make observations and measurements to identify materials based on their properties. (Material properties is emphasized in the first level, but continues to be important as youth select materials based on their properties in each level.)

3–5-ETS1–1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost. (Each challenge involves problem clarification and definition, as well as specification of criteria and constraints.)

3–5-ETS1–2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem. (Each of the levels engage youth to generate and consider multiple possible solutions to problems.)

3–5-ETS1–3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved. (Youth conduct a number of investigations involving the control of variables both to answer scientific questions and to improve their designs.)

Contrasting Junk Drawer Robotics to Other Robotics Programs

The JDR curriculum differs from many other educational robotics programs in several ways. First, the JDR emphasis on "learning through messing about," supported by activities that require common household items (e.g., paper clips, rubber bands, craft sticks, straws), contrasts with other robotics platform kits that require predesigned, prepackaged, and often expensive robotics kits. Avoiding predesign kits and having youth repurpose common items offer more opportunities for creativity. The open-ended approach promotes a materials engineering perspective, which Bennett and Monahan (2013) describe as promoting *materials literacy,* helping children become comfortable with exploring the affordances of different objects, reusability, and repurposeability.

Second, computers are not needed in JDR. While the third level has youth simulating computer programming concepts through group games (e.g., loops, logic statements), there is no actual computer programming taking place. In a traditional educational robotics program, youth build a device (often using predesigned pieces), connect sensors, and program a controller for actions mediated by the sensor input. In contrast, JDR focuses on the scientific and engineering concepts behind robotics but does not extend as far as a specific computer programming language.

Evaluation

JDR was evaluated using three primary methods, including expert review of content, formative evaluations with youth, and an external evaluation field test, described in Mahacek and Worker (2011). These evaluations demonstrated gains in content knowledge around engineering and robotics as well as high levels of engagement and motivation of youth through the curricular activities. We look forward to the continued momentum for engineering education and believe that JDR is a welcome resource for educators interested in science and engineering education.

More About 4-H Science

The 4-H Youth Development Program is administered by Cooperative Extension, a system composed of the U.S. Department of Agriculture, respective state Land-Grant Universities, and county governments. 4-H has a mission to provide school enrichment and out-of-school time community-based youth programs that engage youth in reaching their fullest potential while advancing the field of youth development. The vision of 4-H is to help young people become healthy, happy, thriving people who make a positive difference in their communities.

Since its inception in 1902, the 4-H Youth Development program has created hands-on experiences for youth (ages 5–18) to learn about the natural world, technology, and their communities. In 2011, young people enrolled in 5.3 million science-related 4-H projects. At the core of 4-H's work is a commitment to high-quality positive youth development. This approach requires that young people have access to a long-term relationship with a caring adult, leadership and service experiences, and the opportunity to acquire and use meaningful skills. 4-H programs contribute to youth development and educational outcomes including the Six C's of Positive Youth Development—caring, contribution, confidence, competence, character, connection—and improved science, engineering, and technological literacy, health literacy, and civic engagement.

As the youth development program of the nation's land-grant universities, 4-H is uniquely positioned to address the challenges of increasing STEM (science, technology, engineering, and math) engagement, interests, skills, knowledge, and aspirations among youth. In support of this mission, 4-H has developed a comprehensive 4-H curriculum system that includes standards, professional development, peer review, and diverse learning products in the STEM fields. These learning products are available to all via the 4-H Mall, where more than 50 curricula are offered on topics ranging from aerospace to robotics and more. Learn more at www.4-Hmall.org/curriculum.

In 2008, 4-H launched a bold goal to engage one million new young scientists. To achieve this goal, 4-H built a comprehensive science initiative, with high-quality learning products at its core. This includes a rubric, training, and tools to enhance existing 4-H science curricula and develop new resources. These "Science Ready" standards have helped the 4-H system (1) identify science-focused programs; (2) improve the quality and quantity of programs; and (3) track youth participation in programs that are aligned with these quality standards. In 2012, 4-H achieved its goal of engaging one million new young scientists, with 1.33 million 4-H youth enrolled in 4-H Science Ready programs.

A 4-H Science Checklist serves as a guide for high-quality Science Ready programs. Specifically, Science Ready 4-H experiences (1) are based on the NGSS; (2) develop participants' scientific and-engineering practices; (3) ground learning environments in a positive youth development foundation; (4) are facilitated by educators who are well-trained in youth development and educational practices; (5) use an experiential approach to learning; (6) foster creativity and curiosity among participants; and (7) attend to frequency and duration in nurturing youth outcomes.

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