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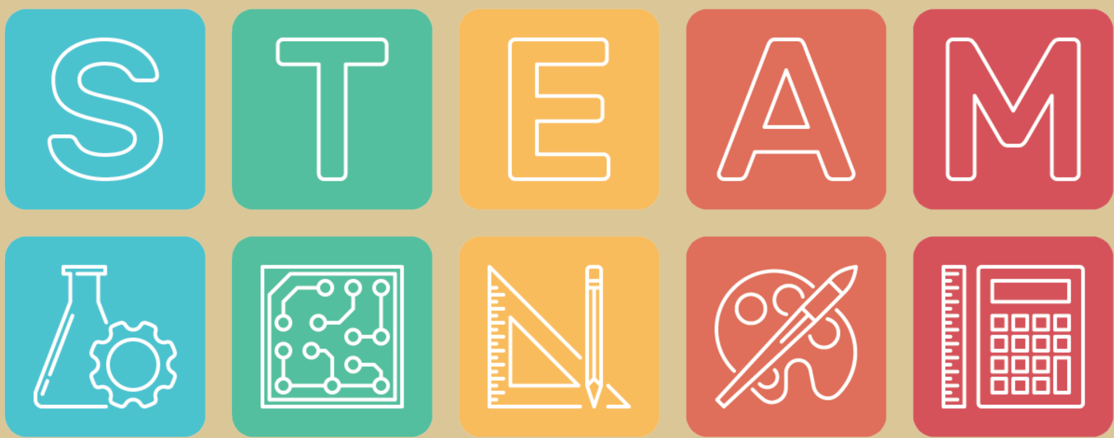
Ministry of Education, Youth and Sport

STEAM Education Based on ICT



Korea International Cooperation Agency

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PREFACE

Cambodian has taken steps toward developing a digital-based economy in accordance with the ever-changing world in the digital era wherein society is rich in information and technological competitiveness, which influence on daily living, work and society. Likewise, Information and Communication Technology is playing a crucial role in responding to the above trend.

In this regard, the Ministry of Education, Youth and Sport has a vision of developing well-rounded human resources with knowledge, skills, especially strengthening ICT skills with a goal to promote creation, innovation, research and sustainable daily problem-solving skill. Strengthening 21st-century skills, science and technology education, digital education, and teacher education institution reform are fundamental priorities in Education sector.

Ministry of Education, Youth and Sport, together with KOICA, has developed nine textbooks for providing pre-service training to ICT-subject trainees at Teacher Education Institutions such as (1) Introduction to Computers, (2) Data Communication and Computer Network, (3) Educational Multimedia, (4) Artificial Intelligence Programming, (5) Database, (6) Python Programming, (7) Informatics Education, (8) Digital Literacy Foundation and (9) STEAM Education based on ICT. These training materials will contribute to the support and implementation of teacher education institution reform throughout strengthening the ICT knowledge and skills of trainers to provide the training to the trainees who will be teachers in the future.

The Ministry of Education, Youth and Sport would like to express a profound gratitude to all stakeholders who have contributed to the compilation and development of textbooks for RTTCs and other Teacher Edcuation Institutions for the benefit of teacher educators, pre-service teachers, learners, and the Cambodian people.

The Ministry of Education, Youth and Sport hopes that these textbooks will be essential learning tools to support the digital economy transformation and teacher educators, pre-service teachers, and learners at all levels for capacity development on technological skills to solve problems in daily life.

Phnom Penh, 07th August 2023

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Preface for STEAM Education based on ICT

This book is about creating new kinds of developmental interdisciplinary learning environments that will be necessary if STEAM (Science, Technology, Engineering, Art, and Math) education reforms are to succeed. The title is a "shout out" to Lev Vygotsky, a developmental psychologist whose ideas I will be referencing throughout the book. (Vygotsky 1978, p. 65). It was collaboratively written by the instructor and students of a graduate-level course titled Instruction for Youth in School and Public Libraries, taught by Dr. Casey H. Rawson in the Spring of 2019 at UNC Chapel Hill's School of Information and Library Science (SILS). This work deepens and extends the work begun in Instruction and Pedagogy for Youth in Public Libraries, an open-access textbook written through a similar process and published in 2018. That text is hosted at publiclibraryinstruction.web.unc.edu.

I am concerned with transforming learning environments into developmental and interdisciplinary ones in this book. The voices of educational innovators who create and collaborate beyond their disciplinary boundaries will be prominent. Conversations and stories are a great way to learn developmentally.

Science. Technology. Engineering. Art. Mathematics. Three of these subjects have long histories in formal K–12 education environments (with technology and engineering being more recent additions to public school curricula). Together, they represent a critical set of literacies that today's children and teens must possess to fully understand the world in which they live—and the world they will help to create. All these learning outcomes were embedded throughout the program series. STEAM concepts and skills were also integrated throughout. For example, engineering concepts and technology were cornerstones of the prosthetic hand project. The design of functional (engineering) and beautiful (art) products was key for the blankets and light-up cards.

These tools allow students to learn by doing and to learn with their hands. Every lesson is either an experiment or a project. Some projects, lighting LEDs, for example, are simple. Others are complex. Laser tag is an excellent example. But simple or complex, only some projects do something if some computer science has been applied to bring them to life.

Throughout this book, I explore a new way of envisioning how a transformation of educational institutions might be possible. I provide accounts of practitioners creating developmental STEAM and STEM learning environments in schools and colleges. The projects featured are not formal research studies but share changes to teaching practice brought about by the specific needs of educators and students.

Content

CHAPTER 1

SCIENCE

In this chapter, you will learn the following:

In this chapter, we describe the conference where we met scientists doing interdisciplinary work using the arts in teaching science. A conversation with an architect who plays with the building blocks of materials and biology will help you understand different aspects of work teaching STEAM.

We will discuss what the term science entails; guide you on how to design your science-specific STEAM programming that will meet the learning goals and/or competencies of the NGSS, the Association for Library Services to Children (ALSC), and the Young Adult Library Services Association (YALSA); and give some examples of science-specific STEAM programming. Science is already commonly included in library programming. With additional intention and knowledge, you can "level up" your science programming to ensure that it is not only fun but also empowering and equitable for young learners.

1.1 What is Science?

Science is one of the key building blocks of our world. It shapes almost every aspect of who we are as a species. It affects everything from the places we live, the products we purchase and use, to the clothing we wear. Including science-based programming in your library is important for multiple reasons: it helps children and teens understand how and why the world around them works the way it does; it educates the next generation about planet-saving subjects like clean energy, waste clean-up, and space exploration; and it can help bridge race and gender-based equity gaps in formal science education environments (Morgan, 2018; Speer, 2019).

According to the Merriam-Webster Dictionary, science is defined as:

- 1: the state of knowing
- 2: a department of systematized knowledge as an object of study in the science of theology
- 3: something (such as a sport or technique) that may be studied or learned like systematized knowledge, have it down to a science
- 4: knowledge or a system of knowledge covering general truths or the operation of general laws, especially as obtained and tested through the scientific method

b: such knowledge or a system of knowledge concerned with the physical world and its phenomena: natural science ("Definition of SCIENCE," n.d.)

Simply put, this means that science is learning something and then putting that new knowledge into action! All you have to do is develop a hypothesis or a question you would like to answer and try to answer it through the scientific method. Can we capture the sun's energy? Let us build a simple solar oven and cook some s'mores! What is sand made out of? Let us gather some up and look at it under a microscope! Can humans fly? Let us jump off something and see! Okay, let us not try that last one, but you can see what we are getting at. Science is an inquiry-based way of examining the world around us that can be done formally and informally. You do not need years of schooling to perform and teach science—just a curious mind and some basic science knowledge.

In K-12 schools, science instruction is guided by a set of learning standards that specify what students should learn and be able to do by the end of the school year. Over the past decade, many states have adopted science standards that move away from rote memorization of science facts toward more process-based standards that aim to help students learn how to use science to solve problems and answer questions. One prominent example of this standards framework is the Next Generation Science Standards (NGSS, https://www.nextgenscience.org/). Developed by a consortium of 26 states and currently used as the standards framework for approximately one-third of U.S. public school students, the NGSS has organized around three dimensions of science learning:

Cross-cutting concepts, such as cause and effect that underlie and connect all scientific disciplines; science and engineering practices, such as developing and using models, that engage students in the real-world processes of scientific work; and disciplinary core ideas that represent key organizing concepts within life science, earth and space science, physical science, and/or engineering (for example, heredity is one core idea within the life science domain).

This focus on the "big ideas" within science and science as an active process instead of a collection of facts aligns well with the types of instruction we already offer in public libraries. Consider, for example, the NGSS Science and Engineering Practice of "asking questions and defining problems." A library program that engages children in the chemistry of slime can easily incorporate instruction related to this practice by inviting participants to experiment with the ratios of slime ingredients to ask and answer questions like "why does some slime rip easily?" or "why is some slime sticky?" You do not need to be an expert in chemistry to lead a program like this; you need to be willing to experiment alongside participants and collaborate with them to ask questions and find the answers.

1.2 Interdisciplinary Problems

In the twenty-first century, the idea of a field in science is not as simple as biologists working on biology. There is a general understanding that science is becoming interdisciplinary. This idea is supported by evidence from analysis of scientific publications.

In 2015, the weekly science journal Nature published a special issue on interdisciplinarity. Proponents of interdisciplinary approaches to scientific research argue that complex problems require teams to work together. How will educators prepare students for work in the sciences? There are no simple answers to questions about what a scientist does.

A different way to think about how students come to participate in the sciences is by taking a brief look at people’s routes to a science-related profession.

Dr. R. specializes in cosmetic dentistry. Growing up, he cleaned toilets to pay his way through college. Today he is a successful dentist, a generous contributor to his community, and a husband and a father putting children through school. He is of Jamaican descent, the first generation born in the United States. Dr. G is retired now, but he often consults with the government on cases related to forensic dentistry. He has authored books and scientific research articles on TMJ (temporomandibular joint) disorders.

Finally, the science and practice of dentistry do not capture the fullness of the lives of the men presented in the anecdotes. If educators succeed at encouraging and inspiring students to consider STEAM careers, starting from student interests and their own might be a promising approach.

1.3 Cultivating Ensembles in STEM Education and Research

The first Cultivating Ensembles in STEM Education Research (CESTEMER) conference was held at the University of Connecticut. A grant funded a research project titled Improvisational Theater for Computing Scientists. Dr. Raquell Holmes is a pioneer in improvisation and performance in developing science research communities.

The number of attendees for the first two conferences has been under 100. Hands-on activities and many include learning theater performance games are offered by presenters at this year’s conference.

The small conference size provides opportunities to foster personal connections with conference attendees. The playful and performance-oriented vision of the meetings created opportunities to experience science learning from new perspectives. Attendees felt that ideas and experiences at the conference could be implemented back at their institutions.

Student engagement in the sciences is a major focal point at the CESTEMER conference. Improvisation, theater games, and the visual arts help develop listening skills. Increasingly, research scientists work on interdisciplinary projects that connect them with colleagues in other disciplines.

Holmes wants people to understand themselves as performers and believes this understanding will allow them to create conditions to change their work and lives. She hopes that people at the conference will engage in a new dialogue of performance, where scientists and science educators can develop relational skills.

1.4 An Interdisciplinary Conversation

Christian Pongratz was the Director and Founder of the Digital Design and Fabrication Program at Texas Tech. Before establishing his practice, he worked for Peter Eisenman and John Reimnitz in New York. He has received awards for his work in interdisciplinary scholarship and teaching.

Students in architecture use digital information to drive the latest fabrication equipment, such as laser cutters, 3D printers, and CNC (computer numerical controlled) routers. These tools are capable of rendering two-dimensional or three-dimensional objects. Pongratz’s talk was about the intersection of architecture, fabrication technologies, information technology, biology, and physics.

Cities will become places where high-tech manufacturing is carried out, says Pongratz. Individuals can create solutions on a small scale using digital fabrication tools. Cities will import digital products from the digital information stream that will be used to drive them.

With digital tools, Nanoscience enables the design of products at the scale of a strand of DNA (deoxyribonucleic acid). According to Pongratz, it is just a matter of time before design happens at the level of atoms.

Pongratz's project is an example of making the means or tools available and creating conditions for people to be curious, playful, and creative. A similar idea, dropping advanced technology into a rural setting and watching what happened, is what Sugata Mitra's work in India explored.

Design thinking is embedded in STEM curricula such as Engineering Is Elementary™ and Engineering by Design™. Design thinking as a design studio pedagogy fosters creative thinking in students, according to Casakin and Mentzer (Casakin et al., 2016).

1.5 Science Education is Changing

Designers are trained to "switch modes of thinking" (e.g., from analysis to synthesis) and address complex problems.

Science and engineering education are being brought together to provide students with more hands-on experiences. Project-based learning and design thinking could improve student retention, satisfaction, diversity, and learning. Significant challenges include cost and commitment from faculty to design thinking pedagogy.

The Next Generation Science Standards (NGSS) for K-12 education have already incorporated design thinking and engineering concepts (http://www.nextgenscience.org/). These standards were produced in a collaborative effort among the National Research Council, the National Science Teachers Association (NSTA), and the American Association for the Advancement of Science and Achieved. These organizations coordinated with 26 states to implement NGSS.

The NGSS is an effort to create national science standards. According to the NGSS Web site, 17 states have adopted NGSS and are working toward state-level implementations.

Pongratz and Holmes describe perfumatory (performatory?) visions of interdisciplinary learning and science education. However, educational leaders and research institutions reinforce traditional learning in the education-for-workforce development paradigm. The epistemic posture in education marginalizes perfumatory and creative approaches to learning.

1.6 The Case for Science

While science may seem to some as the cornerstone of the STEAM movement, some argue that it may be the least important of the STEAM domains. "Most employers are not looking for STEM. They are looking for TEM," wrote current Institute of Education Sciences Director Mark Schneider (2013, para. 14). Schneider argued that "the S in STEM is overrated," noting that national wage data show that "while students in technology, engineering, and math earn more, on average than other students, graduates in the "S" fields in STEM do not" (para. 6).

Science requires us to observe, question, test, and evaluate—to question again and revise our opinions as needed. Science is about continually acquiring new knowledge and holding ourselves and others accountable. Most importantly, it is about keeping an open and curious mind. In a world with overwhelming information, the scientific learning method is more important than ever. (National Education Association, 2018, para. 1-2)

This argument may be persuasive for those who believe that the primary purpose of STEAM education is to help learners obtain high-paying jobs or to fuel the national economy. However, it ignores other, arguably more important, reasons for science education. As a witness in a U.S. Senate hearing focused on scientific research funding, former Scientific American editor-in-chief Mariette DiChristina testified to the less economical, more humanistic impact of science: "Our nation's ability to handle today's pressing issues, from providing energy security to curing illnesses to living sustainably in a finite world, will require the innovations that arise from basic research. Science is a system for exploring and innovation…. it can fire our imagination." (DiChristina, 2014, np) The National Education Association (2018) noted that science education ensures children develop critical thinking skills to help them and their communities thrive. As they wrote, some librarians may avoid science not because they think it lacks value but because they feel personally unequipped to lead science-focused programs. Science can be very technical and complicated, and professional scientists spend years obtaining specialized degrees in their scientific fields. When we think about science, most of us bring things like laboratories, NASA, chemistry, and science fair projects to mind. We think about things that require finely tuned knowledge and specialized tools. However, while science can seem like something that is not for the everyday person, we say it is! As we will see later in this chapter, planning and facilitating successful science instruction in the library is possible for non-experts.

1.7 Science Instruction in the Library

Science instructional programming can come in many forms and flavors. Programs can range from a simple one-shot to a large-scale, multi-session series. For example, the Rochester Public Library in Rochester, MN, created a monthly Science Storytime that combines stories, finger puppets, and hands-on activities (http://bit.ly/2GfcpM0). At the same time, the Curtis Memorial Library in Brunswick, ME (http://curtislibrary.com/) developed an annual seasonal lecture series with hands-on projects, such as creating a solar dehydrator called Sustainable ME. It is up to you how you want your program to look, but we can provide some guidance, tips, and tricks to create smoother and more successful science programming.

If you are starting, we advise you to start small and go slow. Programming can have many variables that will influence what you can and cannot do, such as community interest and needs, your personal experience and knowledge of the subject material, the library's community collaborators and partnerships, and your library/department's supplies and budget. Take your time to consider each aspect as you design your science programming. Using a framework such as the Backward Design model for instructional design can help you more clearly create and design your programming to meet your desired learning goals and still take into account things like budget and collaboration options (see Chapter 9 for more information on instructional design models).

Another framework that might help you design effective science programming is the 5E Instructional Model, developed in 1987 by a team at BSCS Science Learning (https://bscs.org/bscs-5e-instructional-model/). The 5E model facilitates more efficient planning of inquiry-based science instruction by breaking that instruction down into five stages:

Engage: Activate learners' prior knowledge on the topic and make them interested in learning more.

Explore: Learners can interact with the material through hands-on activities, data gathering, model development, or other active learning techniques.

Explain: Learners are asked to communicate what they have learned, using evidence to support their claims.

Elaborate: Learners extend their understanding by applying their knowledge to new scenarios or making connections between the new content and prior knowledge.

Evaluate: Learners reflect on their new understanding and the process that got them there.

Although originally proposed as a linear model, the 5E framework does not have to be a rigid checklist (Vigeant, 2017). You can use it as a tool to structure your science programs in a way that is both fun and educational. An example of a public library program planned using the 5E model is described in the table below:

Table 1. 5E Instructional Model Sample Program

5E Paper Airplane Program	
Engage	Ask participants if they have ever made a paper airplane. What makes some airplanes work better than others? Ask how far they think a paper airplane can fly. Share that the world record for the longest paper airplane flight is 226 feet, 10 inches, set in 2012. Show a video of the record-breaking flight: https://www.youtube.com/watch?v=wedcZp07raE. Then challenge participants to see how close they can come to this record.
Explore	Provide participants with a variety of paper types and sizes. You may also provide participants additional supplies such as tape, scissors, paper clips, and/or instructions for folding various airplane designs (such as those available at https://www.foldnfly.com/). Give participants 15 minutes to design and fold their first plane. Then test the planes, using a strip of tape as the starting line and measuring each plane's distance flown (do this outdoors if possible or in a large room).
Explain	After the first round of tests, get participants talking about which designs were most and least successful and why they think that might be. Compare the design features of various planes and get the participants to hypothesize how to improve their initial designs.
Elaborate	Participants are given another 10-15 minutes to design a new plane using the knowledge gained from their first round.
Evaluate	Test the planes again. Who was able to improve their design from Round 1 to Round 2? What would participants do next time to make their planes fly even farther? How close did we get to the record? Send

participants home with folding instructions for the world record-holding plane (http://bit.ly/2NQPx9Y).

1.8 Formal Programming

Formal programming is designed in detail ahead of time and often has specified learning objectives, planned activities, and adult/expert-led instruction. In the library, this often takes the form of a one-hour (or longer) program offered to a specific user population, such as preschool children or teens. Here are some ideas that can be used for programming that is a little more formal: (https://www.nisenet.org/)

- Learn about chemical bonds and states of matter by using household items to create slime, oobleck, or snow.
- Create differently shaped wands out of pipe cleaners and blow bubbles with them. Discuss how the bubbles are always spherical.
- Learn about the senses by creating sense stations.
- Plant kid-friendly seeds such as beans or pumpkins in small containers and document their growth.
- Learn about chemical reactions by creating mini rockets out of
    - Alka seltzer + water + film canisters, or
    - Mentos + bottles of coke
- Catch rain in two containers (one with a lid and one without) and let the water evaporate and/or condensate to discuss the water cycle.
- Collect leaves from different types of plants and compare shape, size, and color.
- Create and set up a DIY weather station.
- Raise butterflies.
- Look through a telescope at the stars and moon.
- Build terrariums.
- Involve the library in an official Citizen Science initiative, such as water quality monitoring, identification of invasive species, or air pollution analysis (https://www.citizenscience.gov/).

1.9 Informal and Passive Programming

With informal or passive science programming, your library can offer science instruction without having an expert on hand to facilitate activities. Here are some ideas for activities that you could use in ~~and~~ or add to your library as informal science-focused STEAM programming:

- Have a library pet such as a goldfish, bunny, or hamster to teach about animal biology.
- Have backpacks for checkout containing nature walk supplies such as binoculars, bird and plant identification booklets, and local trail maps.
- Build an outdoor sandbox/digging area for children to play in. Add a few tools, such as shovels and rakes. Consider turning it into a dinosaur dig by hiding a few plaster bones or plastic toys and brushes.
- Place some crayons and paper near the door for children to take outside to create nature rubbings. Display their rubbings near this station.
- Set up a microscope and various items for children to look at nearby. Encourage children to bring in their items to examine.
- Download science-themed games or apps on your in-library technology. PBS Kids offers free, well-designed science-themed games and apps.
- Curate rotating book displays that are science-themed (i.e., plants, spring, bugs).
- Have a set of nature-themed toys (i.e., finger puppets, plastic figurines) available for children to play with.
- Have a set of snap circuits for children and teens to play with.
- Plant a pollinator garden.

See the spotlight box below for one example of a public library initiative combining formal and informal programming to bring science instruction to its community.

Summary

In this chapter, you have learned the following:

At its foundation, science is about curiosity. Science instruction encourages learners to ask questions about the world and its impact on it and devise ways to answer those questions. The library, too, is concerned by fostering curiosity among its users, and making science programming a natural fit for our organizational missions and goals. Despite arguments that position science as the least profitable and, therefore, the least valuable of the STEM domains, we believe that scientific literacy is vital for a healthy society and planet. Libraries can be a critical piece of the science instruction ecosystem—where all children and teens can ask questions and find the support they need to answer them.

Question

1. What is the meaning of science in STEAM?
2. How is science used in STEAM?
3. What is science in the STEAM strand?
4. Why is STEAM important in science?
5. What is the science behind STEAM?
6. What is STEAM in basic science?

Additional Reading:

- NGSS Standards: https://ngss.nsta.org/
- Kitsap Regional Library's Designing Steam Guide: https://www.krl.org/bibliotec/our-guide
- How to Create a Robust STEM Library Program: http://bit.ly/2uq4SqY
- ALSC STEAM Power Your Library: http://bit.ly/2ulTIne
- Inspiring & Facilitating Library Success STEAM Activities List: https://iflsweb.org/steam
- STEM Clearinghouse: http://clearinghouse.starnetlibraries.org/
- ALSC Blog: https://www.alsc.ala.org/blog/category/stemsteam/
- Informal Science: http://www.informalscience.org/
- STEM in Libraries: https://steminlibraries.com/
- Show Me Librarian: All Things STEAM: https://showmelibrarian.blogspot.com/p/all-things-steam.html
- School Library Journal STEAM Pinterest: https://www.pinterest.com/sljournal/steam/
- PreKinders Science Page: https://www.prekinders.com/science-page/
- Teach Preschool Science and Nature Page: https://teachpreschool.org/category/science-and-nature/
- Programming Librarian STEM: http://bit.ly/2sMy7nu

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CHAPTER 2

TECHNOLOGY

This chapter, you will learn:

2.1 What is Technology?

2.2 The How of Teaching Technology

2.3 Historical Accounts - Digital Natives

2.4 Andrea's Tech Crew

2.5 Jose Santiago's Family

2.6 Technology in the Traditional Classroom

2.7 One-to-one Computer Initiatives

2.8 Multimedia Projects

2.9 Extracurricular School Programs

2.10 Uneven Spread

2.11 Technology Instruction and the Library "Curriculum"

2.12 YALSA Basic Learning Outcomes

2.13 What Libraries are Doing

2.1 What is Technology?

Technology is “a manner of accomplishing a task, especially using technical processes, methods, or knowledge”. Merriam-Webster’s definition includes language, hand tools, text, non-textual/visual representations, fire, and using a rock to break open a coconut.

In the field of instructional technology or educational technology, the use of computers, information and communications networks, Internet Web sites, and a wide variety of mobile devices are examples of technology used in classrooms. There are also assistive technologies that are specifically used to support learners with a variety of documented disabilities.

Walter Ong describes the transition of human beings from being primarily oral in communications to using text and developing literacy. Ong traces the human capacity to do science, create categories, do logic, and think abstractly to the social transition of people living primarily in oral cultures.

Technology shapes our thoughts and our social, cultural, and emotional aspects. Ong seems to share foundational ideas with Vygotskians that describe how tool use changes our thinking. Despite some obvious unintended consequences, Ong argues that technology is not bad for us.

A dictionary definition of technology is usually akin to “the practical application of knowledge” (Merriam-Webster, 2019). Technology is about anything, from the phones we carry in our pockets to the buildings we live and work in. This makes the technology part of STEAM instruction often particularly difficult to pull apart from the other parts of STEAM education. However, we can pull apart a somewhat distinct understanding of technology to discuss this element. Based on popular STEAM activities that libraries are currently offering, we will classify technology instruction into the following three categories: coding and software creation, technology exposure and use, and learning how technology works (Koester, 2013; Lopez et al., 2019; YALSA, 2019; Shtivelband et al., 2017).

Instruction designed to teach coding skills could be classes or programs that explicitly teach a programming language, such as summer code camps held at a library or activities that teach coding skills. These activities could be computer free, like the cup-stacking exercise above, or they could involve simple computer instructions, such as building paths for easy-to-use programmable robots.

The second category is workshops that aim to expose youth to new types of technology that they may not otherwise be exposed to due to the expense of the equipment or a lack of adult expertise in other aspects of their life. This could include Virtual Reality (VR) technology, high-tech video or photo equipment, 3D printers, or robotics. Sometimes, these technologies are grouped into a specialized maker space, but only sometimes. They could also include software technology, such as Photoshop or web design. The goal here is often to either get children and youth thinking about what they could do with the technology or to help these populations learn how to use it for new goals.

The third category involves learning how technology physically works. This type of technology instruction includes programs such as hosting a robotics team that builds robots of competition, either from scratch or from kits such as those made by Lego robots. Other less formal approaches include basic circuitry workshops and take-apart events, where children and youth take apart old electronics (with safety equipment) from computers to toy pianos to explore how they work (and also often use the parts to make art.)

This three-part definition is not meant to limit public librarians in teaching technology to children and youth but to serve as a framework for how this chapter will approach technology instruction. Librarians should not hesitate to combine tech instruction with other parts of STEAM or to find innovative ways to show learners that technology is all around them. In addition, these categories of technology instruction activities do not need to be mutually exclusive. For example, a robotics team will likely be building technology, learning basic coding skills, and potentially exposing users to new types of technology.

2.2 The How of Teaching Technology

Teaching technology to youth and children in a public library setting is undeniably important. This section will discuss frameworks to get started and look at what libraries are already doing.

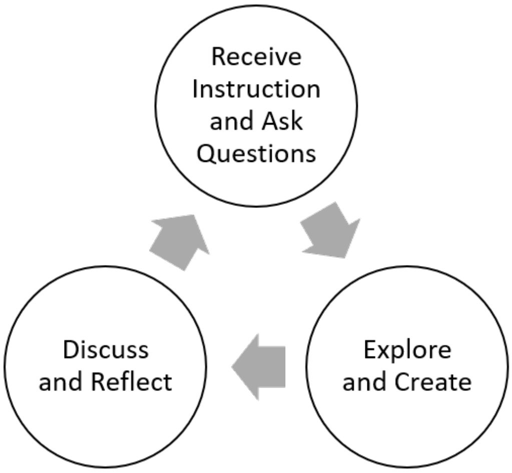

Figure 2.1 Inquiry-Based Learning Process for Technology Instruction

Inquiry-based learning is a natural framework choice for teaching technology in a public library setting. Inquiry-based learning focuses on learning through exploration, with guidance from the instructor to get students started and small group discussions to solidify findings (Kuhlthau, 2010). There are three main reasons that this framework works well for tech instruction. The first is that, because technology frequently changes, giving exact steps to complete an exercise rarely will give students lasting knowledge. Instead, letting students explore will let them develop a deeper understanding of how technology works that they can apply to new technologies later. Secondly, a large part of the impetus for technology instruction in public libraries is the focus on the exploration of new technology that they may not get in a school setting. Inquiry-based learning prioritizes this. Finally, technology has historically been taught with a bias toward specific genders and races. Letting learning be student-driven helps to combat some of these biases. It also makes adding on-the-fly differentiation possible during the exploratory phase, which can be particularly important in public libraries, where it is often unknown if attendees will have particular needs or background knowledge before the workshop begins.

2.3 Historical Accounts - Digital Natives

Marc Prensky popularized the term in a 2001 report titled Digital Natives, Digital Immigrants. He says those born before the digital age are digital immigrants. Teachers who speak an outdated language (that of the pre-digital age) struggle to teach digital immigrants.

Teachers could work with students to build understandings and ways of relating that would not be possible without each generation's unique histories to the learning setting. The assertion that the difference between one generation and another is fluency in the new culture is somewhat dismissive of the experience of immigrants.

2.4 Andrea's Tech Crew

The Young Women's Leadership School of Astoria (TYWLS) is an all-girls school for grades 6–12. This school is the home of an innovative STEAM education program led by Andrea Chaves. In 2016, Chaves received the White House Champion of Change in Computer Science honor.

In the interest of full disclosure, Chaves also happens to be a former student of mine at Tufts University.

The Tech Crew provides technical support to the school's instructional technology. Students work with other students to create an annual Digital Dance program. The Eco-Friendly Fashion show focuses on promoting the importance of recycling found items. Chaves currently works with up to 90 students each year. The Tech Crew students have used the Code.org program as one of their tools to organize the annual Hour of Code.

Younger girls take responsibility for mentoring older girls. Chaves has documented evidence of successful learning outcomes and students graduating high school and going on to college.

Chaves provides an example of what is possible when we do away with the artificial distinctions that divide teachers and students in schools.

Tech Crew is a mentoring program where girls are responsible for teaching each other how to code and for providing technical support to their school by creating new performances. Chaves has no formal training in computer science or small business, yet she received a Champion of Change award for creating these learning environments.

Alexis Chaves is an ordinary teacher doing extraordinary things with her students. She has created a performative environment and a culture where all kinds of zones of development are possible. From my observations of her with students, I can tell that she loves her students and that her students love her.

2.5 Jose Santiago's Family

Jose Santiago has an undergraduate degree in psychology. He currently works in a Brooklyn public school with approximately 500 middle school students. Santiago is the official NYC Department of Education Single Point of Contact (SPOC) for technology support at his school.

According to Santiago, Santiago's first Tech Team was composed of five students. Today, 14 students, who complete a rigorous selection process, currently staff the Tech Team. A classroom-based embedded team model provides more opportunities for students to provide in-classroom technical support.

Santiago believes that students should be able to advocate for themselves. Students understand that they represent the team and hold each other accountable. Students know that Santiago has their best interests at heart and that he will intercede in difficult situations.

Technology teachers are responsible for the maintenance of nearly all of the equipment in their schools. Students are interested in Tech teachers for the access to technology that they can provide. Tech teachers are highly visible in the school community and have flexibility in their Schedules.

Time, flexibility, opportunity, administrative support, student involvement, and a willingness to take risks are all important factors. Chaves and Santiago's willingness to collaborate with students across the digital and generational divide was transformative.

2.6 Technology in the Traditional Classroom

Public librarians must consider what is already being done in traditional classrooms regarding technology instruction to determine the gaps the public library can fill. Students are exposed to technology in the modern classroom in various ways. One-to-one computer programs that aim to provide all students with a tech device such as a laptop have become more common in the last decade. With students having greater access to technology both in school and at home, many school teachers are asking students to complete multimedia projects for classes. In addition, many schools provide students with extracurricular technology opportunities, such as robotics clubs. However, these initiatives are rarely applied uniformly and often leave out those who need access the most.

2.7 One-to-one Computer Initiatives

One-to-one computer initiatives are those where everyone in the classroom can access their computing device. These initiatives are implemented around the country and can start at various grade levels. The most common type of technology used in these initiatives is laptop computers. When adopted effectively by teachers, one-to-one technology can allow students to gain twenty-first-century computing skills and think creatively about technology use. However, they can present initial adoption challenges, especially at the elementary school level, where students must also learn computer basics, such as remembering usernames, to complete assignments (Varier et al., 2017). In addition, public librarians should not assume that one-to-one initiatives equate to equal access. Some students may not have internet access at home or may be limited by parental concerns about technology use. This can serve to widen the access gap between students. Public libraries can supplement the school curriculum in areas with one-to-one computer initiatives by providing students with reliable wireless internet access as a service. Instruction can focus on preparing learners with basic computer skills so that they are prepared once they begin using computers in class and by creating programming that allows students to use technology in exploratory ways rather than to complete a given assignment, as they often are tasked to do in the classroom setting (Varier et al., 2017).

2.8 Multimedia Projects

In many areas, instructors increasingly assign students multimedia projects or options for projects, such as video production or website creation. While this allows students to practice using innovative technology skills, it increases the divide for students who do not have access to equipment at home. Libraries can help by providing internet access and technologies like video cameras to children and young adults. Still, they can also help by providing instruction that exposes students to technologies they might not otherwise explore. This instruction should be user-interest-focused, letting children and youth explore the technology and to base their learning on their personal goals. Classroom projects only sometimes allow students to be as creative or explorative as they wish (Connors & Sullivan, 2012).

2.9 Extracurricular School Programs

Other school-based activities may include extracurricular clubs or teams such as robotics programs or STEAM competitions, such as robotics clubs or some Science Olympiad events. These programs are ideally student-led as much as possible, allowing students to gain valuable team-working, problem-solving skills, and experience with the technologies they are utilizing. These teams are usually voluntary, allowing students to pursue their technological interests more closely than many in-school assignments. They also often touch on various aspects of technology, including coding, building technology, and exposure to new technology. However, these programs are dependent on many factors. Generally, students must have a teacher willing to sponsor after-school events. The school or the students must also have access to materials and a knowledge base to complete the projects. In addition, students must be able to stay after school, which can be difficult for families that rely on bus transportation to get students to and from school. Some clubs may also charge fees or require travel to events or competitions. This cost, combined with transportation difficulties, can prevent many students from low-income families from participating.

While libraries may want to avoid duplicating extracurricular technology initiatives already offered by local schools, they may consider hosting robotics teams or similar clubs if local schools do not or cannot offer them or if offering them at the library would make these initiatives more equitable. This could happen in the library at a time convenient for families, or it could involve librarians traveling to locations that are convenient for students, such as after-school programs, community centers, or even the school itself (Stephen & Locke, 2018).

2.10 Uneven Spread

While technological initiatives in public schools can help prepare students for the future, they are often unevenly available. Often, the areas that could use more technology instruction are left out, particularly rural and inner-city areas. Teachers in these areas need more funding for technology. Since teachers in these schools tend to be less experienced and highly qualified than teachers in wealthier suburban schools, they may also lack the knowledge necessary to teach technology (Garcia & Weiss, 2019; Lynch, 2018) confidently. Students in these areas are also less likely to have access to necessary technology at home. To keep these students from falling behind, public librarians have the opportunity to expand students' exposure to technology. This could come from technology-based instruction inside the library and in partnership with the schools, after-school clubs, and other places youth and children are likely to be. Librarians may also help youth and children by educating teachers on grant-writing opportunities and offering professional development classes (Johnston, 2018; Lopez et al., 2019).

2.11 Technology Instruction and the Library "Curriculum"

Why should public libraries be the place to teach technology to children and young adults? As discussed in the introduction to this book, technology instruction intersects with YALSA learning outcome guidelines, ALSC competencies for children's library staff, and general information literacy standards.

2.12 YALSA Basic Learning Outcomes

The Young Adult Library Services Association (YALSA) has developed a set of Basic Learning Outcomes (http://bit.ly/2mg1x9U) designed to help those working in libraries set learning goals for teen programs. These outcomes focus on putting teens themselves first. Technology instruction can help achieve YALSA goals in a variety of ways. One focus of the guidelines is community and leadership. Students build relationships with their peers and instructors with collaborative technology programs, such as robotics teams or even one-off events where young adults create something together. Some technology programs allow youth to teach one another or younger children technology skills, which allows them to give back to the community and display leadership. The YALSA guidelines also emphasize creativity, learning, and multiple literacies. Technology instruction allows youth to find new ways of engaging in in-person expression and opportunities to experiment and think flexibly, create new content and remix old materials. Understanding and experiencing coding and technology, in general, allows youth to better "think critically about digital tools and their use," another YALSA guideline (YALSA, n.d.). See the Spotlight box below for one example of a public library program that exemplified many of these YALSA guidelines.

2.13 What Libraries are Doing

At the beginning of this chapter, we discussed three types of technology instruction in public libraries. This section will examine what public libraries do in these areas (Koester, 2013; Lopez et al., 2019; YALSA, 2019; Shtivelband et al., 2017).

2.13.1 Coding and Software Creation

Coding and software creation can take many forms in the public library setting. Computerless coding activities, which often involve breaking apart a large task into smaller chunks and then communicating those chunks in order as directions, can serve as a type of "filler" activity in other programs or as their event (in chunks of no more than three different activities) and require no programming knowledge on the part of the instructor. Coding "sandboxes," such as Scratch, allow for coding exploration on a computer without too much prior knowledge required from the learners or the instructors. Small programmable robots, such as Sphero robots, allow for basic coding exploration while being able to be used with a remote control instead, making them easily adaptable to a wide variety of workshops. Finally, primarily for young adult learners, actual coding language instruction in library settings often takes the form of coding camps, which are great opportunities to collaborate with others in the community if your librarians need assistance learning languages.

2.13.2 Technology Exposure and Use

This type of instruction can be extremely varied. The main goal is to expose children and young adults to new types of technology and think about how they can be utilized. Some instruction on how to create content for the technology may also come into play as well. This is where a maker space may come into play if your library has one, but it does not have to. For example, learners could use a 3D printer to make an object based on specifications in an open-source library or learn to make designs themselves. Other instruction may involve media equipment, cameras, or virtual reality technology. Teaching students editing software may also come into play here, as could learning to create and customize a blog to post content. Personal devices are great to add, but only assume some students will have a phone. If working with applications, have tablets or iPods on hand for learners to use and plan to work in groups. Technology can be expensive and should be chosen carefully. Try to pick items, like programmable robots, that can be used in various programs. As long as students think about novel ways technology can be used, anything is fair game.

2.13.3 Building Tech and Learning How it Works

These workshops, often student-led, encourage students to think about how technology works and how it may be modified. For example, some workshops called take-apart parties involve disassembling old electronics and toys to discover how they might work. The independent parts can then be used to create art or something new. On the building side of things, robotics clubs, often student-driven, allow students to create something entirely new. Simpler robotics-building kits from companies like Lego can also be utilized as a simpler in-point to robotics than building them from scratch.

2.13.4 What About Costs?

Cost is a potential barrier to teaching with and about technology in the public library. Individual tech items can easily cost hundreds, if not thousands, of dollars, and libraries must also consider maintenance and repair costs associated with the frequent use of these tools and the ongoing cost of any consumables (for example, plastic filament for 3D printers). These costs may be prohibitive for some libraries, and even well-funded libraries must carefully weigh the benefits and long-term costs of tech purchases to determine their value to the community.

Luckily, not all tech instruction requires expensive equipment. Consider the technology-free coding program described at the start of this chapter, which could be implemented at little to no cost to the library. Some libraries host “tech take-apart” events where older children and teens are invited to use basic tools to take apart broken or nonfunctional technology, including computers, VCRs, modems, and more. You may have items like this at your library already, or you could work with other community organizations to have them donated. In some cases, participants at the take-apart events use components from the tech to create something new (a piece of art, for example). You could also coordinate with your locality’s e-waste recycling program to ensure that you keep the participants and the environment safe while offering this program. Additional ideas for free and/or “no-tech” technology programs are linked below.

Summary

In this chapter, you have learned the following:

Public libraries are uniquely positioned to give children and youth exposure to technology and technology building that they may not get in other areas of their lives. Moving forward allows students to find new ways to express themselves and give back to the community. Technology is all about remixing existing knowledge to make new tools. Hence, as you think about technology in public libraries, consider new things that youth and children can explore and learn.

Question

1. What does technology mean in STEAM?
2. What does the technology stand for in STEAM?
3. What is the difference between technology and engineering in STEAM?
4. How does technology help STEAM students?
5. What are some technology activities?

Additional Reading:

- 5 Hands-On Activities that Teach Coding Without a Computer from ExtendEd Notes: http://bit.ly/2kT3Lf3
- 5 Super-Cool Offline Coding Activities from Think Fun: http://bit.ly/2kSVVSC
- CS Fundamentals Unplugged from code.org: http://bit.ly/2klZRes
- 13 Fun and Free Coding Activities for Hour of Code Week from Teach Your Kids Code: http://bit.ly/2kGWi2S
- Recycled Tech for Teens by Cat Mullen for YALSA's Teen Programming HQ: http://bit.ly/2m0lq4Y

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CHAPTER 3

ENGINEERING

This chapter, you will learn:

3.1 What is Engineering?

3.2 The Maker Movement and Engineering in Education

3.3 Traditional Path in Engineering

3.4 Informal Conversation with Two Young Women

3.5 The Magnet School Approach

3.6 STEM Learning and Special Education

"Maker spaces" are the twenty-first-century versions of a metal shop class. They include everything from 3D printers to wood routers to soldering irons and sewing machines. In some school districts, library spaces are being converted to Maker spaces.

J.E. Martinez argues that schools should adopt the Maker movement in classrooms. Makers share expertise and create partnerships with those who have complementary skill sets to develop ambitious projects. Assessment strategies might focus on "what students have learned" as part of ongoing integrated project-based Maker activities.

3.1 What is Engineering?

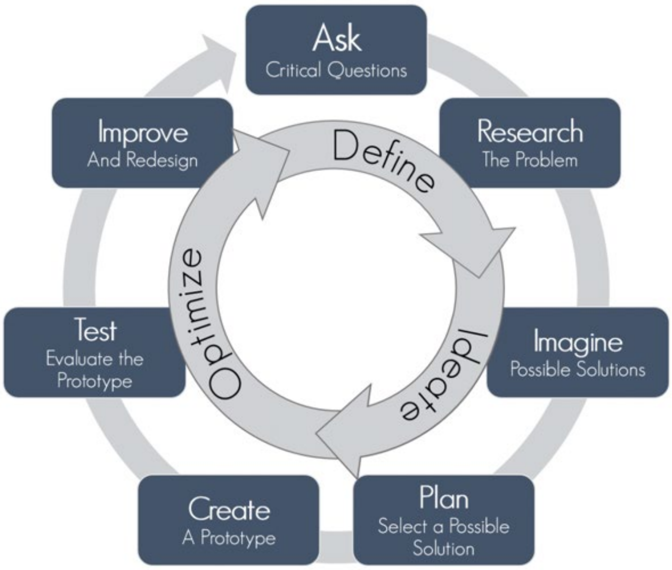

Figure 3.1 Adapted from https://www.techengineering.org/k12engineering/designprocess

Among all of the STEAM domains, engineering may be the most practical. Engineering can be broadly defined as applying science, math, technology, and design to solve real-world problems. The National Research Council distinguished engineering from science by stating that science is

Focused on asking questions and constructing explanations, engineering focuses on defining problems and designing solutions (Committee on a Conceptual Framework for New K-12 Science Education Standards, 2012). Even more than in the other STEAM domains, engineering education is focused on processes and practices versus memorizable concepts. Specifically, this discipline is concerned with the process of engineering design: an iterative approach to problem-solving that involves defining a problem space, imagining multiple possible solutions, then testing and refining those solutions over multiple cycles. This process is summarized in the diagram below, adapted from the Engineering Design Process model created by Teach Engineering (https://www.teachengineering.org/).

Although distinct from the other STEAM domains in some ways, the National Academy of Engineering emphasized that engineering relies on science, math, and technology to support design activities (Katehi, Pearson, & Feder, 2009). The arts are just as critical to effective engineering design since many engineered products are developed as much for form as for function (for more on this, see the next chapter).

3.2 The Maker Movement and Engineering in Education

The Maker movement comprises engineering enthusiasts, artists, craftspeople, and entrepreneurs. It is a "do-it-yourself" entrepreneurial environment that is finding its way into educational settings. Many educators view the Maker movement as an entry point to engineering education.

3.3 Traditional Path in Engineering

The preparation of engineers begins in high school. Students with strong academic standing in mathematics, physics, and science apply to engineer schools in a competitive application process. Upon graduation, entry-level jobs are obtainable. However, obtaining professional licensure is recommended.

Some students who exhibit early interest in engineering can participate in specialized programs. While there is a movement to increase the number of young women and minorities entering the engineering fields, there may be some work yet to be done on developing alternative pathways into engineering.

3.4 Informal Conversation with Two Young Women

In 2012, I co-taught a Career Discovery course in the School of Engineering and Computing Sciences at NYIT. Young women and young men were coming/~~seemed~~ to do engineering work with different stories and interests. Some had been building computers and repairing mobile devices for years.

Innovative educators are creating opportunities for students to engage in hands-on STEM and design activities in primary school settings that might help them compete later. While these educators may not use words like "performance," what they describe are new performances in school for themselves and their students.

3.5 The Magnet School Approach

According to the U.S. Department of Education Web site, The Magnet Schools Assistance program provides funding to public schools in the U.S. One of the themes that Magnet School administrators have prioritized is the creation of STEM-themed schools. There are significant challenges for educators who take on the task of turning existing schools into STEM-themed schools.

3.6 STEM Learning and Special Education

Gina Tesoriero is a special education teacher who provides STEM education experiences for students. She is a member of the New York City Common Core Math Fellows. She has co-authored two publications and has presented at national conferences on STEM education.

The New York Hall of Science (NYSCI) is a science museum with many science education and teacher professional development programs. They host an annual Maker Fair and are committed to helping bridge the gaps between informal science learning and science learning in the school environment.

Darensbourg and Tesoriero are creating opportunities for students of color and students living in poverty to be exposed to engineering concepts and STEM activities. They show that innovation and creativity are possible using experiential learning strategies, including hands-on, project-based learning.

Summary

In this chapter, you have learned the following:

The world will always need people who can identify problems and find workable solutions, whether or not those people are professional engineers. This recognition has led to the gradual, incomplete, and unequal incorporation of engineering education into the public school curriculum. Teaching children and teens to use the engineering design process might help them obtain an engineering job one day, or it might simply help them approach their challenges more systematically and with more tolerance for ambiguity and failure. However, it is difficult to argue that this type of education is not valuable. Libraries can help bridge gaps in the quality and quantity of engineering education that children and teens receive, especially when we focus on the processes and practices of engineering rather than its more technical aspects.

Question

1. What does engineering mean in STEAM?
2. Why is engineering important in STEAM?
3. How much do STEAM engineers make?
4. How do you become a STEAM engineer?
5. What is engineering in simple words?

Additional Reading:

- Engineering design activities from Teach Engineering: http://bit.ly/2SJpYdU
- Design challenges from Technovation Families: https://www.curiositymachine.org/challenges/
- Engineering design activities from Try Engineering: https://tryengineering.org/teachers/lesson-plans/
- Engineering design challenges for libraries from STARnet: http://bit.ly/2SGhu71

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CHAPTER 4

ART

This chapter, you will learn:

4.1 What does the "A" Contribute to in STEAM?

4,2 Performance and Preparation

4.3 A Playful Interdisciplinary Artist

4.4 Vygotsky, Creative and Art

4.5 Dismantling Some Arts-in-STEAM Stereotypes

4.6 Arts-Based STEAM for All Ages

4.7 Culturally Competent Arts-Based STEAM

This chapter will explore how STEM became STEAM, then explain how arts-based STEAM programs can relate to learning goals and/or competencies within the current Common Core State Standards (CCSS), the Association for Library Services to Children (ALSC), and the Young Adult Library Services Association (YALSA), all of which have some influence over how school and/or public library programs are designed. The second part of this chapter will focus on schools and public libraries across the nation that are currently incorporating arts-based STEAM into their programming. Finally, we will present tips for integrating arts-based STEAM into your public library programming and what variables you should consider to ensure that your programs are culturally competent and inclusive of youth from all backgrounds, ages, languages, abilities, and cultures.

4.1 What does the "A" Contribute to in STEAM?

Key Point

As STEAM learning becomes part of the curriculum, educators must make practical choices about how integration will happen. Who gets to make those decisions, and how will those decisions be made? These are good content-related and administrative questions that cannot be answered in the abstract.

The acronym STEAM came into widespread use in the early 2010s, after then-President of the Rhode Island School of Design (RISD) John Maeda and his colleagues began advocating for the incorporation of the letter 'A' for the 'Arts' into STEM pedagogical practices. The arts can include visual arts such as drawing, painting, sculpture, and computer graphics; performance arts like dance, singing, and poetry; and more. In a 2012 interview, Maeda made the case that "extending STEM to STEAM by adding art makes sense, because STEM by itself is extremely powerful. Its scale is amazing. But that alone does not create warmth and humanity and connection" (Roach, 2012, "How do you accomplish that at RISD," para. 3).

Since Maeda's initial call for a shift from STEM to STEAM, many other artists, STEM professionals, and educators have embraced the idea. In his 2015 article, aptly titled "An Artist's Argument for STEAM Education," Curt Bailey argued that arts integration could add beauty, emotion, and eccentricity to STEM work. He noted that products have as much functional and aesthetic appeal as they do emotionally. For example, you might decide on a new car based not only on its technical specifications but also on its design and how it makes you feel: excited, playful, responsible, daring, and safe. STEM professionals who do not understand the emotional impact of their designs may arrive at solutions and products that are functional but not interesting or desirable. In terms of eccentricity, Bailey argued that art helps people learn to be comfortable with the out-of-the-ordinary, allowing us to design things that are not just out-of-the-ordinary but are extraordinary. As he summarized, "art is the discipline that most celebrates, encourages, and embraces the original and creative" (Bailey, 2015, para. 9). See the callout box below for a quick example of an out-of-the-ordinary product design.

4.2 Performance and Preparation

Author J.E. Martinez creates an imaginary scene featuring two college professors and actors. The actors are Kim Snyder and Marian Rich, who perform as a business executive, and a woman performing as a cabaret entertainer. In the middle of the interview, Martinez asks for applause.

Kim and Marian seem open to creating new performances with science and math. Students in performative learning environments become scientists and are doing work and becoming chemists, and engineers. It is possible to use predetermined tools without being predetermined by them.

4.3 A Playful Interdisciplinary Artist

Yuko Oda is a visual artist and professor of fine arts in New York. Oda earned her M.F.A. from the Rhode Island School of Design. Her animations, installations, sculptures, and drawings have been exhibited at many art galleries.

Computer animation would be impossible without the computer, and computer science is without artistic purpose if an artistic voice does not emerge. Oda leads her students in the process of discovery that encourages them to engage in the uncertainty of creating something new.

Oda's experience as a kindergarten teacher is fascinating because she provides an example of the development that Newman and Holzman describe. Oda's interaction with young children provided a chance for them to experience how play and art, not being predetermined by the process, come together in a creative activity.

4.4 Vygotsky, Creative and Art

N. Catherine Connery (2010) notes that Vygotsky's dissertation attempted to address the psychological questions related to art. He was interested in art's potential to curate psychological problems. His early work resonates with our discussion of art and the powerful force of "artistic vision".

Oreck and Nicoll (2010) note that "complex relationships are involved in the development of dances and dance artists." This idea about teaching art bears a resemblance to what Yuko offers when she works to develop the "artistic vision" of her students. The pressure to intellectualize connects with Yuko's description of having a "playful spirit."

Lois Holzman (2010) notes that Vygotsky made a distinction between the zone of proximal development (ZPD) of "play development" and the ZPD of "learning-instruction development." Holzman suggests that difference does not need to be as sharp as Vygotsky describes.

In Vygotsky and Creativity, editors Ana Marjanovic-Shane, M. Catherine Connery, and Vera John- Steiner offer the following critique of education. The very structure and practices of our K-12 system restrict, retard, or prevent imagination, play, and creative ingenuity.

4.5 Dismantling Some Arts-in-STEAM Stereotypes

Perhaps because the integration of arts and STEM domains is still relatively new, several misconceptions about arts, STEM, and the library are common.

First is the idea that all arts-based programs are STEAM programs. If that were the case, virtually every public library could say that they already offer extensive STEAM programming since arts and crafts activities are common in existing programming for kids and teens. As discussed in earlier chapters of this book, STEAM is all about integration across domains, emphasizing their points of connection and interaction. A program where kids listen to a story and then draw the characters might be engaging and instructive. Still, it probably is not a STEAM program unless intentional connections to STEM domains are included. The example programs described later in this chapter highlight instruction that includes, or even focuses on, art but also integrates science, technology, engineering, and/or math.

Another misconception is that deciding to include the arts in your STEAM programming will somehow take away from the learning opportunities that your science, technology, engineering, or math programs already have. Each discipline has its unique purpose, time, and place. Pairing one or two with art may seem clunky and forced at first. However, the ultimate goal of this integration is to improve and enrich your STEM instruction by providing learners with a different way into this content than they might have been offered in formal education environments. Likewise, STEM content can improve and enrich arts instruction as learners understand how many of our perceptions of beauty, style, and proportionality are rooted in scientific and mathematical principles and formulas.

One final misconception is that some people are not creative and will not enjoy or excel in arts-based programs (either as the instructor or as a participant). However, I believe that you—yes, the reader—are creative and have a place in arts-based STEAM education! We each have individual talents and experiences that we bring to our jobs, as unique as our fingerprints. No matter your age, skill level, training, or prior appreciation for the arts, it is essential that you recognize the fact that you are creative (in one aspect or several aspects) and identify your passion(s), such as music or web design. Once you are in touch with your passions, you can work those into the programming you provide and enjoy facilitating the experience even more. You cannot be a maker until you feel like a maker and know you are one.

4.6 Arts-Based STEAM for All Ages

Arts-based STEAM programming can be implemented with children and teens of all ages. For example, one art-based activity for elementary-age students is "Build the Library!" which has children recreate their local library or another local building out of Legos (Pard, 2018). You can have the children craft blueprints, decide on the building's size, and brainstorm what sized Legos will fit best in certain areas. Then you can display this building in a display case in the children's section or the front of the library (Pard, 2018).

Arts-based STEAM programs are great candidates for regular weekly or monthly programs. Some examples of these types of programs are a Knitting/Crochet Club (combining math with art) and a Lego Club (combining engineering and art). These programs are great because they are easily customizable to fit the age group you are working with and are easy ways to solicit community partnerships. For example, suppose you want to host a Knitting or Crochet Club for middle school students. In that case, you can invite local community members who enjoy crochet and/or knitting to teach children how to make a simple hat or scarf by following a YouTube tutorial (combining technology, math, and art). All you need to do is provide the craft supplies and physical space. This type of activity gives the children access to hands-on instruction, counting and literacy comprehension experience (such as counting the number of stitches and reading the crochet/knitting pattern), and the ability to take the project home, work on it, and bring it back the following week to receive constructive feedback and more instruction.

You can host a weekly Creative Writing afterschool program for middle-grade and high-school teens focusing on STEM themes such as outer space, technological dystopias, or disease pandemics. These programs are also great opportunities for collaboration. You could invite local/regional authors or English teachers to lead writing or brainstorming sessions. Again, this builds a friendly rapport between community members and allows them to showcase their talents and assist others in developing their writing skills. This can also be a chance for students who are normally underrepresented in libraries such as English-as-a-second-language (ESL) patrons to participate and create written pieces in their native languages in an affinity or caucus group.

Arts-based STEAM programs can also be offered as one-shot events or passive programs. For example, you might offer a nature drawing program with a guided walk outdoors accompanied by botanical illustration instruction. Alternatively, you could include a sketchbook and charcoal pencils or watercolors in "nature walk packs" available for checkout at the library desk, encouraging users of all ages to incorporate art into their outdoor adventures.

4.7 Culturally Competent Arts-Based STEAM

Library science researcher Patricia Montiel Overall (2009) defines cultural competency as "[…] a highly developed ability to understand and respect cultural differences and to address issues of disparity among diverse populations competently" (p. 176). As a LIS professional, you should not only be consciously aware of the many cultures and experiences your patrons bring to the library but strive to acknowledge, support, and educate others about these cultures and experiences in the programming you provide, including your STEAM programming.

Since art focuses on personal expression, it offers rich opportunities for culturally relevant instruction. One way to do this is through hosting a Culturally Relevant Storytelling program (CRS), which invites children to use colored paper, markers, scissors, and technology—such as Stop Motion video—to create stories in response to prompts about their own lives or books read during story time (Hunter-Doniger, Howard, Harris, & Hall, 2018). Such prompts could include, "Where are you from?", "Describe your family's culture," or "What makes your culture special/unique?" These prompts are broad enough that children can easily come up with answers that they can then illustrate to tell an engaging and informative story that other program attendees can learn or compare and contrast their stories with too, depending on the participants' ages. With the participants' permission (and their parents or guardians'), finished projects can be displayed in the youth/teen area or near the library's front entrance to showcase the diversity of cultures in your community. "When invited to explore artistically, [children] can access their imaginations, pushing the boundaries of their own cultural identity into a space that is unfamiliar," which will no doubt educate other children and spark new conversations and understandings about differences (Hunter-Doniger, Howard, Harris, & Hall, 2018, pg. 47).

Arts-based STEAM programs should not subliminally cater to one specific demographic of a larger diverse population. Tween or teen patrons who identify outside of the dominant gender/sexual binaries, race/ethnicity/culture, or language in your community may not feel as welcome at—or may even feel like they are excluded from—certain arts events because they do not see an aspect of themselves reflected in the program. These reasons could include their identity being misrepresented or unrepresented by the instructor or guest of the event, the event's activity or theme(s), or the language and imagery with which the program is promoted. One way to change this dynamic is by inviting local or regionally identified LGBTQIA+, Black, Indigenous, and Person of Color (BIPOC), and/or English-as-a-second-language (ESL) authors, visual and/or performing artists or community organizations to partner with you in hosting arts-focused STEAM events. You can also dedicate a certain area of the library, such as a section in the Youth/Teen area, for minority youth to form affinity groups, safe and brave spaces where they can gather together and share their thoughts and experiences that might be separate from the program's dominant participants. No matter our age, we all want to feel like we belong somewhere. If your library can be where that feeling of belonging occurs for disadvantaged youth, that should make your programming even more powerful.

Lastly, it would help if you considered external factors or barriers that may impact one's ability to attend your arts-based STEAM programs. Factors like socioeconomic status, transportation, familial obligations, or work/school schedules may require you to switch the hours of an arts-based STEAM event or host it off-site so that all who want to attend physically can access the space. Suppose your library is one branch of a larger regional system. In that case, you can partner with other branch libraries to host certain events, similar to what the APL did earlier in this chapter with their "Teen STEAM" events. If you are a smaller library in a rural area, you can bring these events to nearby schools and work with the school district to create after-school programs. These modifications not only make events physically accessible for those that struggle with transportation or mobility issues, but ease anxiety or "otherness" that patrons may feel in a traditional library setting.

Summary

In this chapter, you have learned the following:

Over the past decade, with the addition of the Arts into STEM pedagogy, STEAM has evolved into a national movement to prepare youth for higher education and/or career readiness, as well as instilling in them the importance of the arts in everyday life. Public library arts-based STEAM programs represent a unique opportunity to provide free access to arts-making materials and technologies that children might not have available at home or school. Furthermore, community partnerships can be incredibly effective for arts-based STEAM programs in the library. Building relationships with local/regional talents, including writers, artists, and musicians, can show youth that a lot is possible outside of the 'traditional' STEM fields. These programs will be much more enjoyable and long-lasting for all youth who attend if they can see themselves reflected in the program's material, theme, or participants.

As Andrew Watson (2017) has said, "STEAM is more than a lesson or class; it is a culture focused on engaging students to solve real-world problems" (p. 15). Arguably, the public library is the perfect place where students can engage in this culture of problem-solving through artmaking in an informal learning environment. As our world's problems become increasingly complex, we must continue providing external resources, personal guidance, and access to STEAM programs that are not only arts-inclusive but also considerate of all cultures, experiences, and abilities. The options to incorporate the arts into STEAM are endless—you might have to be creative about it.

Question

1. What is STEAM in art?
2. Why are the arts important in STEAM?
3. Why are arts a part of STEAM?
4. How is art used in STEAM?
5. Is art a STEAM career?

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CHAPTER 5

MATH

In this chapter, you will learn:

School boards and school districts determine the mathematics that we learn in school. The National Council of Teachers of Mathematics (NCTM) is one of the primary influencers of math standards. Publishers use math standards to outline what students should be able to do at the end of a course of study.

NAEP Trends in Academic Progress report provides trends on reading and math assessments dating back to the 1970s. Over 43 years in mathematics education, we have improved achievement levels for 9- and 13-year-olds. But those gains do not translate into higher performance by the time students are 17.

Spending, curriculum, standards, and teacher preparation have changed over the past 43 years. We may need to look at how we teach math and evaluate the outcomes of instruction. I hold very little hope that data-driven instruction will change mathematics education.

5.1 What "Mathematics" Means for Library Instructors

As we have already seen, librarians only somewhat universally beloved math. While more evidence may be needed to state conclusively, Baek (2013) suggests that much of this anxiety is a product of a lack of qualification. Librarians often come from non-STEAM – especially non-math– backgrounds and thus feel apprehensive about teaching math as "non-mathematicians." Kliman, Jaumot-Pascual, and Martin (2013) suggest that mathematics is seen as "without context" (i e., divorced from the "real world"), and librarians' math anxiety is often a result of a narrow or incomplete conception of what math is.

Let's briefly consider just what math is before turning to the specifics of planning and leading math instruction in libraries. The traditional understanding of what counts as math is likely something akin to Dudley's (2010) view of mathematics as "algebra, trigonometry, calculus, linear algebra, and so on: all those subjects beyond arithmetic" (p.608); in essence, math is applied arithmetic and the more esoteric formulations beyond those subjects covered in primary school. While this definition is certainly not incorrect, it is limited, and more helpful ways exist to approach this question. Hersh and Ekeland (1997) offer a more organic articulation that might be better suited for our purposes: they argue that math is the name we give to a set of social objects. Rather than being a set of natural laws "out there" in the universe waiting to be discovered, math is a human-created system that we can use to understand the universe and solve problems. The rules, figures, concepts, and math problems are occasionally grounded in some physical reality, but most often, they are shared social conventions. For example, we typically use the base-10 or decimal number system (with digits from 0-9) in everyday life, but some cultures use a base-8 system, and computer programmers use a base-16 (hexadecimal) system. There is nothing fundamentally more "natural" about base-10. We have agreed as a society to use this system for most mathematical applications.

Understanding math as a human-created system may help alleviate math anxiety somewhat. If math is the name for a set of social objects and librarians already perform countless social tasks, then librarians likely already possess substantial knowledge about math and math instruction. Math is already part of every story-time, especially those with shapes, numbers, or sizes; math happens in every Lego club; math undergirds every maker space. In short, libraries are full of math already, and librarians make that math happen. Our true challenge is recognizing those objects and knowledge and channeling them into action.

5.2 How is Math Taught in K-12 Schools?

Before exploring how math can be incorporated into library programming and services, we will briefly discuss how it is currently taught in public K-12 classrooms. If you haven't been in a K-12 setting since 2010 or so, math instruction likely looks very different now compared to what you experienced as a student. That is due to the national adoption of the Common Core State Standards, which has transformed math and Language Arts instruction in the United States.

Rather than teaching students the quickest way to solve mathematical problems or the one "right" way to solve a problem, Common Core math aims to help students understand mathematical operations and the relationships among them conceptually. This often involves teaching students multiple approaches to the same mathematical operation, focusing on the process as much as the answers, and encouraging argumentation and logical reasoning. With that said, it's important to understand that the Common Core is a set of standards – benchmarks for what students should learn and be able to do at each grade level. Common Core is not a curriculum. It does not dictate what happens in individual classrooms to help students reach those standards. Many complaints about Common Core math shared on social media and in the news are about the materials used to teach the standards rather than the standards themselves (search "Common Core math memes" if you're not already familiar with them).

The center of the Common Core math standards is a set of eight Standards for Mathematical Practice that cut across all grade levels (http://www.corestandards.org/Math/Practice/).

These standards, like the Next Generation Science Standards (NGSS), emphasize mathematical processes rather than specific operations or “facts”:

1. Make sense of problems and persevere in solving them
2. Reason abstractly and quantitatively
3. Construct viable arguments and critique the reasoning of others
4. Model with mathematics
5. Use appropriate tools strategically
6. Attend to precision
7. Look for and make use of the structure
8. Look for and express regularity in repeated reasoning

Also, like the NGSS, these standards connect to the skills we already teach in the library. For example, YALSA Teens First Learning Outcomes such as “Teens can think flexibly” and “Teens can show perseverance” (http://bit.ly/2mg1x9U) aligns well with the first two standards above.

Although Common Core math has been in place for nearly a decade, the jury is still unsure whether it has improved student learning. National research studies have found mixed results on this question, though Common Core proponents point to several reasons why the evidence may not yet point to its unqualified success: teachers are still getting used to the new curriculum, classroom materials continue to be refined, and improved, and national tests such as the National Assessment of Educational Progress, may not accurately measure the thinking that Common Core is trying to develop (Barnum, 2019). Regardless, Common Core math is here to stay.

Now that we have discussed math and how it is taught in schools, we can move on to more specific strategies for incorporating math instruction into public library programming and services.

5.3 Performance of Math Conversations

The tables and chairs were arranged in a large U-shape with the open end pointing to the front of the room. Group-based learning was a norm in our school, where students worked collaboratively.

Students discussed the properties of numbers that I had forgotten or never learned. Professor Smith only asked questions and did not indicate whether what a student said was right or wrong. It had been a long time since I had been in middle school, and this was all new to me.

J.E. MARTINEZ and J.R. SMITH were both parts of the New York City Teaching Fellows program that provided us with alternative routes into teaching. Unlike many math teachers, Smith was a professional mathematician and gifted math student.

The Common Core State Standards for Math should help teachers create a more developmental learning environment. In my teacher's class, I saw students imitate how she led group conversations. Mathematics became a complex social activity, something that everyone could be organized to do.

5.4 It is Hard to be Developmental

Vincent Accardi is a mathematics teacher in New York State who has been teaching math using the Common Core State Standards, and he is also a student of mine in a graduate course. Below are some of his posts in an online course (edited for clarity). He shares some of his thoughts on why math is hard to learn in school despite standards that encourage developmental approaches:

Post 1

In math, students attempt to understand the problem before trying it. Students use drawings, graphs, and physical models to help solve problems. As much as we don't want to admit it, we teach the test with deadlines and due dates.

Post 2

Collaboration is something that I tried to stay away from in my education. Collaboration and group success are what I celebrate now. There are always winners and losers in the classroom. Some students must feel the same way when they enter a classroom, which is sad.

Post 3

Students are graduating with a memory of procedural fluency that will almost certainly be lost within a few months. "Conceptual understanding" is a phrase that's tossed around. According to J.E. MARTIN, most students need to have all the conceptual understandings they should.

He identifies teaching to the test, competition in math, and the need to cover material at a certain pace. His self-identify movement went from being competitive and not collaborating to encouraging collaboration.

5.5 Brains Pre-Equipped for Doing Math in Social Settings

We are all born with what is referred to as number sense, and we do not need language to experience numbers. Research conducted by Gallistel and Gelman has led them to compare human and non-human cognitive mechanisms in the number sense. The researchers assert that non-verbal tools for mathematical reasoning develop at the same time that children become aware of the world.

In the 1980s, Jean Lave conducted studies that contrasted the abilities of shoppers to do mental mathematics calculations while shopping with their abilities to do the same calculations in school. Lave found that shoppers who considered themselves poor math students performed better in the supermarket than in conditions that felt more like a test.

Barbara Rogoff argues that human cognition (including mathematical cognition) is situated in social practice. According to Rogoff, these guides could be peers and adults who explain, discuss, model, observe, and influence how children participate in cultural activity.

Vygotskian theory suggests that mathematical reasoning is as social and natural to human beings as our capacities to use language and technology. Creating more opportunities for "math talk" in the classroom may help students and teachers create new math performances in classrooms.

A student who achieves 100% on a test receives positive reinforcement and is expected to maintain that level of achievement. Students who receive a grade less than 100 are challenged to do better. The testing system competitively ranks students against each other rather than creating an apples-to-asters.

Students ask questions about the relevance of math instruction throughout their K-12 experiences. When mathematics is part of social activity, including shopping, play, and puzzle solving, the question of relevance disappears. Mike Askew suggests providing students with opportunities to rehearse in the classroom before being asked to present.

5.6 Performative Tool

The Math Video Project is a relational "tool and result" type tool. The project created "new wants," which should not be confused with motivation. Jeff Lisciandrello created new wants for himself and his students with assessment and training technology in the math classroom.

The following dialogue is from a meeting with Lisciandrello, a former student of mine. He was a fifth-grade math teacher in New York City. He describes his experience using technology to transform math learning and assessment in his classroom. The dialogue has been edited for clarity.

Lisciandrello provides the Light Bot™ software as a fun and interactive mathematical activity. The software provides students with multiple attempts at problems. It provides targeted information based on what types of challenges and activities the student succeeds at and those that present a struggle.

Lisciandrello's students responded differently to his attempts at interventions. Technology enabled him to look at his students' situations in new ways. He says that grouping is less evident when students are allowed to work collaboratively on a project-based learning project.

Carole Anne Tomlinson is often credited as being a leader in the differentiated instruction movement. The idea behind self-instruction was to make schooling fit the child, not the other way around. This revolutionary moment in education gave way to the established institutional order of the time.

Differentiation attempts to develop different entry points to the same concept or the same learning task. Jeff Lisciandrello discovered this when working with two boys and technology in his math class. In contrast, we can create learning communities with many tasks and no goals.

5.7 Why Math Learning is Hard

The performative approach prioritizes building relationships with math as a social activity. This includes conversations, project-based learning, and performing math in everyday contexts. Teaching math in a way that transforms it into a social activity should be both collaborative and celebratory.

5.8 Mathematics Programming for All Ages

Although math instruction may get much more complex at higher levels, it can begin with something as simple as learning concepts like "less and more" or counting to ten. This means that math instruction in the library can begin with programming for our very youngest users.

5.8.1 Preschool

Math education for preschool-age children is one area where librarians may already be well prepared. Moreover, this is one of the areas where library instruction in math can make the biggest difference for learners, as evidence suggests fostering math skills at this developmental stage is strongly correlated to long-term academic success (Park, Bermudez, Roberts, & Brannon, 2016). For learners in this age group, math instruction is often intended to develop students' number sense (Baroody, Eilan, & Thompson, 2009), which has three sequential components: first, developing counting strategies using objects or words (i.e., inductive reasoning); next, reasoning skills that add patterns and relationships to those counting processes (i.e., deductive reasoning); and last, retrieval strategies that move those earlier skills to long-term memories which learners can more easily recall. Outside of number sense, mathematics instruction in this age range also fosters spatial-geometric sense and interest by emphasizing the exploration of shape and size (Sarama & Clements, 2004). These three stages rely on skills that libraries and librarians regularly help develop.

With an understanding of the skills we are looking to develop, let's consider a successful example of mathematics instruction for this age group to see some of the tools and techniques available to library instructors.

5.8.2 Elementary School

As children transition from preschool into primary school, the challenges posed by and approaches to mathematics instruction in the library change considerably. While preschool-age math instruction tends toward fostering mathematical literacies through abstract connections and properties (e.g., "shapes," "sizes," "numeracy," etc.), math instruction for elementary school-age children tends toward further developing those skills through concrete, explicitly "mathematical" tasks (i.e., "math problems") (Stein, Grover, & Henningsen, 1996). However, while the materials themselves are more definitively mathematical, the ideas they express are considerably more abstruse. A student, for example, can easily understand that the elephant in the story is larger than the cat; she can refer to the pictures, she may have a direct experience to reference, or the story itself might provide contextual clues with which the student can deduce the answer. That question becomes significantly more esoteric when presented symbolically using numerical representations of the animals' respective sizes.

Complicating matters further, one now needs to reconsider the purpose of library mathematics instruction given these changes in form and content. In her literature review, Frederiksen (2009) found that libraries and librarians tend to see the role of their instruction as both a supplement and complement to the curriculum and standards of their local schools. Moreover, since this is the age group in which math anxiety most commonly begins occurring, libraries and library instruction can be the relaxed, fun environment children need to overcome those anxieties and successfully internalize mathematical concepts (Spencer & Huss, 2013).

With the understanding that mathematics library instruction for this age group can reinforce and expand the local standards and curricula and act as a low-stress environment to help ease math anxiety, let's now examine a successful model of mathematics instruction for elementary school-age children in the library.

5.8.3 Middle Grades

The differences in needs and considerations between elementary school-age children and those in the middle grades are subtle but significant. The aims and purposes for library math instruction are generally similar between these two groups. Frederiksen's (2009) findings seemed to be as applicable to learners in this age range as they were to their slightly younger counterparts; that is, library instruction for learners in this age range tends to be a matter of reinforcing and supplementing the school curricula for these learners. The key difference for librarians is that the subject matter may be slightly more sophisticated and abstract.

Crucially, however, there are some additional affective and ethical concerns for teaching these learners one should consider. Students' self-perceptions seem to become a major determinant of success in this demographic (Pajares, Britner, & Valiante, 2000), and this is the age at which learners begin to report seeing math as useless or impractical (Parajes & Graham, 1999). Two possible implications for instructors are the potential inclusion of multi-goal lessons into a curriculum so learners can feel successful early and often in the process and working to tie those lessons to "useful" real-world situations. Moreover, learners in this age range can handle and benefit from multi-tiered problems (Van de Walle, 1998). One of the desired math competencies for this demographic is an ability to answer problems requiring iterative thinking.

Finally, we should consider library math instruction for middle-grade learners relating to our technological and educational conjuncture. Responsible and proficient computer use is doubtlessly an important skill for learners, and evidence (Herro, Quigley, & Jacques, 2018) suggests that this age group is ideal for developing those understandings. These learners likely have the mathematical thinking capacities and the broader intellectual and emotional sophistication to begin handling both the technical and ethical aspects of computer use. Furthermore, as Spencer and Huss (2013) demonstrated, the library can provide the ideal, low-stress environment for grappling with ideas challenging to learners on both cognitive and affective levels.

Since we have now seen how the needs of middle-grade learners closely align but remain critically distinct from those of elementary-age learners, let's revisit the model we examined for the latter group and see how one can adjust that program to suit the needs of an older cohort better.

5.9 Teens and Young Adults

Much like the leap from elementary-age to middle-grade learners, the needs and considerations for math instruction for teenagers and young adults are like those of middle-grade and elementary-age learners but distinct in key ways. Perhaps the strongest similarity between teens and their younger counterparts is the benefits of contextualizing math instruction. Stressing math's importance in life after primary school ends is particularly beneficial in math instruction for teens (Burress, Atkins, & Burns, 2018); for instance, Tyson, Lee, Borman, and Hanson (2007) found that exposure to math in a STEM-career focused context in high school is a powerful predictor for whether a student will obtain a bachelor's degree in a STEM field.

Beyond career and higher educational implications, however, library math instruction's value for teens —especially today's teenagers—is a matter of rectifying a social-contractual failure for which teens are now paying the price. As Harris (2017) noted in his exhaustive evidence survey, primary education in the 21st Century has been defined by two major federal policies: 2001's No Child Left Behind Act (NCLB) and 2009's Race to the Top (RTTP) program. While each policy differed in its specific requirements, enforcement mechanisms, and aims, Harris observed that they shared two common characteristics: an emphasis on standardized testing as a means of evaluation and the push for universal learning standards. These two factors profoundly changed education for learners, shifting classroom time towards the dreaded “teaching to the test” and a classroom focus on the subjects those tests measured – STEM and language arts. Perhaps unsurprisingly, Harris found that the increased quantity of math education was the pure quantity and nearly no quality math instruction. For example, he found that much “math” instruction focused on successfully eliminating incorrect answers on tests to increase the likelihood of randomly selecting the right answer to a problem. Furthermore, teens bear the brunt of these negative consequences, as their education has been entirely within this framework. Since the compulsory portion of their education is ending, they may not see an alternative model.

This is where math instruction in the library can make a profound difference. Since the library was and is not subject to these mandates, it can provide the stimulation and exploration schoolroom instruction can no longer afford to offer. Moreover, as the Pew Research Center (Horrigan, 2015) found, the people most likely to use the library or attend a library program are those disproportionately burdened by math anxiety and instructional inequalities: women, people of color, and low-income households. Thus, one of the greatest benefits of library math instruction –for all ages, particularly teens and young adults– is that it provides meaningful math instruction; an opportunity increasingly rare in other educational settings.

With the role and importance of math instruction established, we should now consider one effective model for library math instruction for teenagers.

Summary

In this chapter, you have learned the following:

Math anxiety is an unfortunate reality of math education, at least as presently constructed. It is likely that both you, the library instructor, and your learners at least occasionally struggle with it. The goal of this chapter was not to provide a cure for math anxiety but rather to develop a program of math anxiety mindfulness to limit its effects on library math instruction. Our plan for combatting math anxiety involved situating math and math instruction in the right conceptual framework, identifying helpful library resources and exploring options for collection expansion through low and no-cost means, and examining the needs and considerations of different age groups matching them to exemplary programs. Successful math instruction, however, does not end with overcoming math anxiety.

As librarians, mathematics is not likely to ever be your favorite subject (Kliman, Jaumot-Pascual, & Martin, 2013). However, you will also likely encounter learners for whom math *is* a favorite subject. Moreover, a three-year longitudinal study of 20 schools found that students who rank mathematics as their favorite subject often feel as though they are alone in their preference and, thus, atypical or unusual (Attard, 2011). That study also found that regardless of preference, students saw a “good” math instructor as: (as what? Passionate?)

Therefore, the final component of successful math instruction is bringing genuine enthusiasm for math to your lesson plans. Whether you find some property or branch of mathematics that sparks your interest in the subject or enthusiasm for fostering a love for mathematics in your learners, truly excellent math instruction comes from passionate math instructors.

Question

1. What does math mean in STEAM?
2. What are the 5 components of STEAM?
3. Why is math important in STEAM?
4. How is mathematics related to STEAM?
5. What kind of math is in STEAM?
6. What is the importance of math for you as STEAM students?
7. What are the 7 foundational elements of STEAM?

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CHAPTER 6

THE EDUCATION FOR WORKFORCE DEVELOPMENT PARADIGM

In this chapter, you will learn the following:

- **6.1 Introduction**
- **6.2 Weak Links**
- **6.3 Accountability and Achievement**
- **6.4 Standard**
- **6.5 Don’t Reform, Perform!**

This Chapter explores various approaches to building a positive interdisciplinary STEAM (science, technology, engineering, arts, ~~arts,~~ and math) learning environment as described by educators across the K-20 educational ladder. Crucial to their success, Martinez finds, is the playful and performative approach they employ in their teaching.

6.1 Introduction

Using the idea of a paradigm as a lens for viewing the purpose of education in the USA helps make the complex social structure and limits of policies, practice, and problem domains visible. How the USA approaches STEAM and STEM education is presented here by reviewing how leaders and practitioners address STEAM education knowledge and practices challenges.

STEAM is an acronym for Science, Technology, Engineering, Art, and Math. Some definitions indicate that STEAM stands for art and design; others suggest it stands for architecture. This book uses the definition of STEAM in a congressional resolution of May 1, 2015.

The STEM Education Act became law in October 2015. Among other things, the Act provided funding for prospective teachers to apply for scholarships and for the NSF to fund education research in informal learning settings. The report states that more support for STEM education is necessary to develop a STEM workforce for manufacturers, high-tech companies, and small businesses.

Congressional resolutions and various committee reports are how policy advocates communicate their views, practices, and understandings of STEAM and STEM education. As stated in the STEM Education Act of 2015 report, the primary concern is to improve how the future workforce is prepared to fill "in-demand STEM jobs".

6.2 Weak Links

Michael S. Teitelbaum's book analyzes questions related to American competitiveness in the STEM disciplines and workforce demand. He concludes that there is no consensus among researchers about the preparedness of the US workforce to meet the needs of national interests. His book provides a historical analysis of STEM workforce funding that he describes as "alarm-boom-bust".

Teitelbaum argues that "boom" and "bust" funding for science, education, and research has led to a crisis in global economic competitiveness. The US federal government shutdown in 2013 is an example of a bust event that unexpectedly constrained discretionary spending at NSF and the National Institutes of Health.

In chapter after chapter, Steven Teitelbaum challenges the certainty of general assertions regarding STEM labor shortages and educational failure. He argues that the USA is still competitive despite the limitations of inconsistent federal funding cycles, misalignments in workforce development, and overstatement of workforce needs.

Teitelbaum: No evidence that improving student achievement in school will lead to improved national competitiveness. Lowell and Salzman's report suggests we should be concerned about addressing the learning of students performing at the lowest levels if improving the international ranking of students is the primary issue.

This selective review reveals that in dialogue with business and government, the scientific and education research community is responsible for raising the alarms and delivering the alarmists' critique. According to Kuhn, scientists' response to a "crisis" is to identify where the discrepancy is in the field. "The problem is labeled [sic] and set aside for a future generation with more developed tools" (Kuhn 2012, p. 84).

6.3 Accountability and Achievement

The previous discussion of the education for workforce development paradigm highlighted reports framing the debate about education problems. The practices that currently dominate conversations about teaching and learning include measurement of accountability and achievement, standardizing curriculum, and improving the qualifications of teachers.

The No Child Left Behind legislation of 2001 (NCLB) was an education reform designed to increase teacher accountability. In 2016, the Obama administration admitted that its revision to NCLB mandates, known as Race to the Top, fell short of having the desired impact.

The problem of student achievement gaps in science and mathematics is another significant concern pursued in the education for workforce development paradigm. Despite all the money, efforts, and improvements, gaps persist. There is some utility in defining gaps to motivate educational reform. NCLB legislation linked standardized testing results to criteria for judging teaching effectiveness in schools.

6.4 Standard

The fourth definition in Merriam-Webster's online dictionary for the word standard reads as follows: something set up and established by authority as a rule for measuring quantity, weight, extent, value, or quality. Standards work very well in manufacturing environments where processes and materials are controllable. The education for workforce development paradigm provides the framework for preparing students to participate in work environments. Measuring student performance is not just desirable but necessary for determining whether or not students are achieving expectations. It may be helpful to illustrate how standards come into being with an example from mathematics education.

The National Council of Teachers of Mathematics (NCTM) is concerned with advocacy, research, professional development, teaching and learning standards, issues of access and equity, and practices. The common Core State Standards initiative was brought about by the need to grant waivers to continue federal funding to states that could not meet NCLB performance standards.

6.5 Don't Reform, Perform!

Many educators will relate to STEAM and STEM education legislation and funding efforts as the latest in a series of workforce competitiveness reforms. They will use the tools they have always used and work on problems like they always have. We can expect those efforts' good and bad results to be recognizable as attempts at refining existing ideas about teaching and learning and measuring achievement. The frustration that people experience with education reforms and policy will likely continue. How could it be otherwise if the same tools and ways of looking at problems continue to be used? A new way of creating change is needed.

Uncritical acceptance of what I have described as the education for workforce development paradigm will make it hard to embrace new ideas and create new practices in STEAM education. The school system works for some students and some teachers and only works for a few students and teachers. Everyone agrees that more creativity and innovation in schools is desirable; it is in the congressional record. In my experience, thinking of innovation and creativity as something that needs to fit into existing practices is the wrong approach. When innovation and creativity happen in an institution or a learning activity, a transformation occurs, and everything changes. STEAM educators are calling current teaching practices into question as they create new interdisciplinary practices and ways of being in educational institutions. Their actions, projects, and new relationships are the critiques or the new performances that underscore our need to go beyond reform to achieve/create/realize the transformation of educational institutions that we are all hoping for.

Summary

In this chapter, you have learned the following:

There's a reason we talk about "steam" programming as opposed to "s-t-e-a-m" programming: just as these five letters combine to form a single word, the five domains they stand for can also combine to create instruction and programming that is more than the sum of its parts. Whether your library integrates just two of the STEAM components in a program or all five, encouraging children and teens to see the connections among them, and to make new connections themselves, needs to be at the heart of your work. The challenges and issues facing today's youth will require cross-disciplinary approaches. And on a more positive note, the interests and passions of these children and teens can also be enriched when they are equipped to make connections across subject areas, as illustrated by the many program and activity examples shared in this chapter.

In the following five chapters, we will explore each of the five STEAM domains separately, looking at how these subjects are taught in school, their relation to information literacy and other library-related content, and considerations for integrating this content into library instruction. As you read these chapters, we encourage you to keep these connections in mind.

Question

1. What are STEAM education pedagogical approaches and practices?
2. How was STEAM Pedagogy used as an approach for teacher professional development?
3. Integrating Art and Engineering: What do faculty think?
4. What factors influence teacher quality and quality teaching and their effects on student achievement? Four areas are examined in this report and describe what is known about preparing quality teachers and their impact on K-12 student achievement in mathematics and science.
5. Please explain the 6 steps to achieving the new leadership development paradigm.

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CHAPTER 7

METHODOLOGICAL APPROACHES TO STEM/STEAM LEARNING

In this chapter, you will learn the following:

7.1 Introduction

A teaching method is a tool that can be reused to achieve a planned result or outcome. Teachers benefit from professional development (PD) opportunities schools and school districts provide. School administrators can motivate teachers to take PD classes/seminars/training in new methods.

7.2 Thoughts on Centeredness

A "teacher-centered" methodological approach to creating learning environments features the teacher as the prime motivator of what happens in the classroom. Teacher-centered methods include the lecture, using the blackboard or electronic whiteboard, reading to students, demonstrations, and questioning students. The teacher also decides (as far as the students are concerned) what topics will be studied and how students will learn them. The progressive education and curriculum design movement has trended away from teacher-centered approaches to student-centered ones. Student-centered approaches have been proposed to organize teaching in school systems since the late 1890s to address the specific learning needs of students (differentiation) and to respond to low student achievement in schools (Franklin 2005). Most student-centered approaches to teaching allocate the majority of time in a lesson for students to be engaged in cooperative or collaborative activities with peers.

"Centeredness" in learning environments means that there is a focal point around which instruction revolves. Whether teacher-centered or student-centered, classroom instruction obscures or oversimplifies the complex cognitive, social, and emotional interactions teachers and students have. I have heard many educators claim that practice in the classroom is student-centered. However, it is impossible to determine what is going on in the classroom simply because it has been labeled "student-centered."

I see "student-centered" as a shortcut for describing what happens in the classroom. This shortcut to communicating may be helpful when we do not want to or need to take the time to provide the specifics of student-centered activities. The shortcut does not help when trying new ways of thinking or innovating in the classroom. What I do think will help is teacher narratives. I've noticed that teachers tend to tell stories about what goes on in classrooms. The stories contain detailed descriptions of social interactions in the classroom. Sometimes there are interesting digressions to provide listeners with historical background, and there is often a point being made about teaching in that particular circumstance. These narratives are a genuine and powerful means of engaging adult and youthful learners. To create developmental STEAM learning environments, we will have to tell each other stories. In the next section, I will tell an ironic story about learning to use project-based learning (PBL) as a methodology in the classroom. Training in project-based learning has emerged as a popular method for preparing teachers to use student projects to make STEM and STEAM interdisciplinary learning fit into the existing curriculum. PBL training comes with a system of forms and instructions to produce a documented process (unit plans and lesson plans) that will ultimately result in descriptions of student learning outcomes tied to explicit learning goals, standards, and products demonstrating evidence of learning. What follows is an experience observing and participating in teacher professional development that features project-based learning.

7.3 Project-Based learning Professional Development

During the summer of July 2014, I was invited to attend three all-day professional development sessions with elementary teachers. The focus of the professional development was to initiate the creation of PBL unit plans. The trainers were knowledgeable and could bring computer technology and lesson planning resources to bear that are useful in various schools.

Typically, attendance is taken at the beginning of a PD workshop. Teachers drink coffee, eat bagels, and workshop organizers hold off on starting the day until they get close to the expected number of attendees. When that happens, the workshop organizers start making introductions and remind teachers to sign attendance sheets to receive what is known as "per-session" training pay. The workshop leaders introduced me as a researcher and university-based partner on this occasion. I had an opportunity to introduce myself and speak about some of my priorities, and I took a few minutes to teach and play an improvisation game. The game "Yes, and" creates a collective story and is designed to help players listen to, accept, and build upon the conversational "offers" that others may contribute to telling a collective story. This is a good game to play when I anticipate being in environments where many people will begin their comments with "No, but" or "Yes, but," which work to negate what has been said and brings conversations to a halt or initiates a dispute. The "Yes, and" collective story is one of my methodological tools for creating developmental learning environments.

The workshop plan was for the participants, all pre-K–5 teachers from three different elementary schools, to work in groups and use instructional technologies, such as laptop computers, the Internet, and Google Apps for Education, to develop STEM-based PBL unit plans. Their PBL plans required identifying a problem and developing a curricular unit that resulted in solutions to the problem. They were required to produce documents using PBL management templates and Web-based resources set up by the school district to provide teachers with easy access. In addition to the materials listed above, teachers had curriculum maps (a schedule of the content to be taught each month) for the grades they taught and the appropriate Common Core State Standards.

As teachers began to work, I became aware of some resistance to the new ideas and some of the work. Some teachers rejected offers of help. Some teachers seemed to be working on using the PBL framework to retrofit classroom projects. Others appeared to be continuing work started in an earlier workshop. Many teachers I worked with had chosen their comfort zones as a starting point for a PBL-integrated lesson and were trying to identify a relevant problem to associate with the project unit they were developing. Over the 3 days, even as the teachers became increasingly comfortable with the PBL framework, they struggled to align the standards, curriculum, and ideas. Many teachers experienced frustration at trying to "make it all fit" into their existing understandings of their teaching contexts. I hoped people would remember the "Yes, and" performance when they wanted to say "but." However, many sentences started with the word ***but.***

7.4 Disequilibrium

According to some of the research literature on teacher professional development, disequilibrium is necessary for teacher learning (Opfer and Peder 2011; Wilson and Berne 1999). For teachers to learn something new, existing practices and beliefs must be challenged. Teachers' responses to the PD were consistent with the research literature. Some teachers demonstrated "resistance" to the experience. I interpreted the failure of participants to make eye contact with the lecturer, their reluctance to ask questions, and their tendency to make statements that began with "but" to be an indicator of this.

Another phenomenon identified in teacher professional learning research is that teachers will not adopt new approaches unless they see the benefits regarding improved student achievement (Adey et al. 2004). During the workshop, some of the teachers I interacted with expressed concerns about making PBL structured projects fit within the realities of a school day, meeting the expectations of administrators, aligning projects with standardized testing, and teaching the students. Many teachers who referenced standardized testing said they could not see how PBL prepared students for the test. Given these conditions, it was reasonable to expect teachers to resist adopting new technologies and methods until they saw the benefits.

Interdisciplinary connections across content areas are part of the natural progression in a PBL unit plan. Teachers with more experience and subject-matter expertise had less difficulty seeing interdisciplinary connections than less experienced teachers. One group of less experienced teachers admitted that they needed more research for their interdisciplinary unit on the migrations of native North American peoples. If the goal of a PBL unit is to generate a process of inquiry, why did teachers feel they had to know the answers in advance? Why could not students and teachers discover things together?

The relevance of instruction to students' lives is another key feature of PBL instructional units, and was one of the objectives of the U.S. Department of Education Magnet Schools grant that funded the teacher professional development at the school I was visiting. Teachers decide what students will learn based on the curriculum and standards in these workshops. It needed to be clarified how much input students or the community expected to have in these units. In my interactions with some teachers, it was unclear whether they had an understanding of the socioeconomic realities of the community they worked in or how their social class biases might lead them to take certain things for granted about the lives of their students when making decisions about the relevance of PBL units. For example, one group planned on having third-grade students create a travel brochure for visiting the Galapagos Islands. I couldn't see how the lesson plan related to the lives of the children in that community, and those connections would still need to be made in the lesson plan if indeed they could be made.

I observed that experienced teachers could increase pedagogical options in the PBL plans of less experienced teachers, and they seemed willing to share and provide guidance. The beneficial impact of experienced teachers on novice teachers is consistent with some research findings (Adey et al. 2004).

PBL is process-oriented, inquiry-driven and presumes an iterative development cycle. The tendency of some traditional approaches to teaching is toward facilitating knowledge acquisition by explaining and motivating students to complete the task. Some units ended with a final assessment of whether or not student-created products met the criteria established by standards. Workshop leaders noted during the workshop that starting the actual hands-on project work at the end of the unit as the assessment instrument was an indicator of teachers' thinking in more traditional terms. The PBL process uses hands-on activities to raise questions throughout inquiry learning units. Based on my observations, it was evident that many teachers in the room did experience dis-equilibrium and were struggling with new ideas. At one point in the workshop, one facilitator did remind teachers of the “Yes, and” story in response to a series of statements where different teachers were saying, “but.” It is not the first time I observed someone reaching for an improv method in a moment of frustration.

7.5 Dispositions

During the lecture portion of each day, I observed many teachers with “eyes on screens” or who refused to make eye contact with the speaker. This was frustrating for the trainer, evidenced by the phrase, “You need to pay attention to this.” One possible explanation for this behavior is that the teachers were multitasking. I am sure that many workshop participants would claim to have been multitasking. I did see some laptop screens showing emails, the PBL forms, and other relevant-looking materials. Another explanation, as previously noted, is “resistance,” which may be due to indifference, embarrassment at not knowing the material, being unprepared, or being bored. Alternatively, trainers may have mistaken a lack of eye contact for lack of teacher understanding. Teacher resistance is a source of frustration in PD environments for trainers and workshop participants. The professional development literature helps explain and diagnose teacher resistance, its forms, and possible treatments. But getting to the root causes of the symptoms is not one of the things that can easily be accomplished in a PD workshop.

I engaged in conversations with several teachers and was heartened by their enthusiasm and willingness to plan to take risks with the material. Several of these teachers had already been given formal leadership roles as Magnet School specialists. These were senior teachers who self-selected and interviewed for teaching positions that would be funded through the Magnet Schools grant. These teachers were highly motivated and willing to take on significant challenges, and their performance at the workshop differed from many participants. Other teachers were being paid by the hour during the summer to be in the workshop, but their performances told different stories about their reasons for and comfort with being there. This was a clue to moving beyond describing and diagnosing teacher resistance and understanding it.

There are many approaches to providing teachers with support in examining their expectations for students and their beliefs about learning. The best type of support comes from peers and opportunities to reflect openly on teaching practices. In this professional development workshop, there was a plan to provide opportunities for reflection and to use the Critical Friends protocol for feedback. The Critical Friends protocol originated from work at the Annenberg Institute for School Reform at Brown University. It is a professional learning community designed to structure peer interactions to improve teaching (Moore and Carter-Hicks 2014). The Critical Friends process has a set of protocols, including implementing a "tuning" protocol as a first step that provides the group with practice in going through each of the steps together. The outline described by Moore and Carter-Hicks specifies 68 min from the introductory activity to the closing debriefing (Moore and Carter-Hicks 2014, p. 7). However, circumstances drove workshop facilitators to cut short the feedback and reflection portions (20min) to cover PBL curriculum development issues. Time for reflection and feedback was traded away for covering the curriculum. I have participated in the Critical Friends protocol and have observed others using it. I view the protocol as a highly scripted ensemble performance. I was an observer, and the interactions seemed a bit rushed. It was hard for me to determine how anyone felt about the process. I think the reflection portion is as important or almost as important as the content/curriculum of the workshop.

I think understanding how people felt about the process would (1) help improve the process and (2) probably provide insight into what the takeaway for teachers was.

The 3-day PBL workshops proceeded along familiar patterns and would be recognizable as being of high quality despite the varying levels of enthusiasm. The teachers responded along the lines predicted in the literature on teacher professional development. A few days after the workshop, I gave workshop organizers feedback on the training. The specific feedback is irrelevant here; I responded to them with suggestions from a best practices perspective. My goal was to continue building my relationship with these teachers and schools, which meant I had to work with what they offered, which was an opportunity to provide useful feedback on their terms.

Many teachers feel like they need a choice regarding professional development, and choices are difficult for PD trainers to create. Empowered teachers, such as those identified leaders (the Magnet School specialists) in a PD workshop environment, will exhibit enthusiasm. The Critical Friends protocols can work when they are routinely part of school teacher practices. In my experience, teachers believe there are opportunities for choice-making and risk-taking in schools where new ideas take hold. Teachers are also receptive to new ideas if they think that administrators trust them and that they can trust their colleagues.

Schools should invest the same effort in creating trusting environments as they do in developing professional knowledge and other professional practices.

7.6 Systematic Approaches

Based on my observations of efforts in STEM education, PBL will be the approach many schools will take toward STEAM education. Collaboration and creativity in classrooms will also be encouraged in STEAM teaching and learning. However, it is still being determined whether creativity and collaboration will be central to STEAM education practices or be viewed as add-ons to what I regard as a systematic approach to learning in schools. Systematic approaches to learning in school sequence and coordinate learning activities. A measurable outcome can be described when the learning process is broken down into distinct steps. For example, "the student will be able to write her name" is a measurable outcome.

The differences become apparent when we compare early childhood learning to formal school-based learning, such as toddlers' engagement. The developmental performative learning of children outside of school may include, for example, a child's exploration of a living room. Exploring a room by a child has many possible outcomes, some that are observable and others that are not. The outcomes of exploration may not be measurable. What a child learns while exploring the room may not have direct, causal relationships to what develops and is not predictable.

In a systematic learning activity, for instance, in a kindergarten classroom, a morning routine might involve children signing into the class by writing their names in crayons on a large sheet of paper. Name writing is reinforced through the systematic instruction of the alphabet, posting the children's names on personal items, and having them practice writing their names on worksheets and other items. As the school year progresses, teachers will document each child's ability to write her name and form the letters of the alphabet. The expected outcome of instruction and immersion in text production is a child who can write her name, recognize letters, and form and space the letters to create words. There is no doubt that a system of learning helps with measuring learning and ensuring that students have opportunities to learn the things that are a priority. However, a systematic approach to learning only recognizes or values the expected outcomes. We cannot discover other important things about children using systematic methods. Fortunately, kindergarten and other elementary school teachers do many things that are, in my view, performative.

7.7 Performing With(in) a System—A Slight Digression

The morning sign-in activity is a non-threatening, formative assessment strategy that is also fun for the students. Elementary school teachers perform many unsystematic formative assessments of children and their families in daily interactions. For instance, elementary school teachers note how parents and children perform the morning routine. They consciously and unconsciously track changes in the routine, noting troubling drop-off incidents, children who look sick, or changes in the drop-off caregiver. Any change to the routine may trigger an improvisational response from the teacher. I've known many excellent elementary school teachers who are great improvisers and astute observers of children and families. Those skills and approaches to assessment are performative and vital to creating welcoming and safe environments for children. In less happy circumstances, where teachers have much less autonomy and do not perform, bureaucratic (systematic) responses prevail, and there is little evidence of development, improvisation, or good conditions for learning. I have worked in hard-to-staff schools, failing schools where the systematic approach to learning dominates, and there are many unpleasant trips to the principal's office. I have had many conversations with teachers about "the system," where they tell me that the system does not allow them to teach, much less perform in the ways I suggest. I encourage them to perform within the system and play with the system. I further remind them that teaching is a political act, and they have a civic responsibility to be advocates for children and families.

7.8 Irony and the PBL Workshop

A pedagogical approach like PBL prioritizes and documents what is to be studied. A PBL may involve many well-defined tasks to produce one or more expected STEAM learning outcomes. However, if PBL outcomes must be predetermined, how will the possibilities associated with unplanned learning be recognized and valued? More important, if PBL and other recently used methods in progressive education are reused for STEAM, would there be justification for expecting different results than those for STEM or other initiatives to improve math and science learning?

Ironically, the PBL method was not used to teach teachers in the professional development session described earlier in the chapter. Professional development workshops are product oriented. Teachers must produce unit plans for teaching, and the workshop is a process for production, not a process that prioritizes inquiry or facilitates the involvement of stakeholders (members of the community, students, etc.) in developing the unit plans. For teachers, learning the PBL method can get disconnected from practicing the method. To be sure, many teachers produce PBL units that are engaging and efficient in this manner. However, I question the sustainability of this approach. The PBL system generates a significant amount of documentation that details what students need to do, how activities will meet standards, and how student performance will be assessed. Unit plans also include listings of required materials, interdisciplinary connections, differentiated strategies, and expected outcomes. Teachers will tend to reuse and perhaps revise units, but what will occur when there is a change in the curriculum or the standards? What will happen when a second-grade teacher is reassigned to teach the fourth grade, and her PBL units are no longer relevant? Will she be offered someone else's fourth-grade PBL units? Will she find them appropriate for how she envisions teaching the fourth grade? What will happen when funding for teacher PD and new curriculum development efforts ends? One of the major challenges of having any system is ensuring that it can be maintained in the face of changing conditions or assumptions. Another challenge of systems is that they encourage more systems, which can lead to fewer opportunities for creativity and autonomy.

Despite my questions about the PBL approach, it is possible to use systematic approaches creatively. We can play and perform with and within the system if we need to. The value of project-based learning is that it does provide students with hands-on learning experiences. When a PBL unit is ambitious and well-designed, there are opportunities for collaborative learning experiences with peers and adults inside and outside the classroom.

7.9 Experiential Approaches

Project-based learning provides a type of experiential learning. Experiential learning can include but is not limited to field trips, collaborative research projects, internships, service learning, and study abroad experiences. Descriptions of experiential learning usually include something other than imaginative play, rule-based play, team sports, improvisational performance, theatrical performance, and organizing public exhibitions. I believe the play and performance activities that I've added to the list are all forms of experiential learning that should be part of any approach to developmental STEAM education. Experiential approaches to learning provide students with opportunities to reflect on what they are doing and learning. The reflective process of experiential learning can be about more than generating a piece of writing that will be submitted at the end of a lesson. Reflection can be a part of an ongoing process that informs creative development. What I find most powerful about experiential approaches to learning is that they often occur in a "real world" context.

When the outcomes are not overly predictable or predetermined, students must bring the entirety of their being to bear on figuring out what they need to do, not just report on some knowledge they acquired. However, even experiential approaches to learning can be made to be as systematic as any other kind of approach. What makes one approach to learning systematic and another unsystematic or performative?

The Math Video Project discussed earlier was designed as a developmental, performative approach to learning. I could not predict the outcomes and did not predetermine what learning standards would be met. Furthermore, I couldn't claim that I "knew what I was doing" because I had never done it before. I was confident that something positive would come out of it because students were supported to collaborate, use new tools, and have complex challenges relevant to their lives.

If I were to make the Math Video Project systematic, I would determine specific content knowledge covered by all videos. For example, using seventh-grade math content, the theme of the videos might be to understand the concept of pi. Each video would have to meet criteria that aligned with learning standards in mathematics and presentation skills. Each team member would be assigned specific roles in the project and would be responsible for specific tasks. There would be a test at the end of the production of videos to confirm that everyone learned something about pi. I would still expect various videos, but they would all be about pi. The students still have opportunities for choices, fun, and engagement because they use technology.

The overall experience would be different because I have done projects with students using performative developmental approaches and systematic approaches. Students and teachers can become very comfortable with systematic approaches to learning because they know what to expect and what is required. Knowledge is acquired incrementally, and progress is predictable and measurable as long as a student stays caught up.

When I have used performative approaches with middle school students, I upset the order of things. Students will ask questions about the requirements when they see a few. They will express uncertainty about whether they are doing their projects correctly. Students will often discover that certain approaches to a project can lead to dead ends. Students tap into their areas of strength, and some discover things about themselves that they would like to improve. Many students are often more self-critical about their performances than I would ever be of them. A performative approach to teaching is more fun and interesting, and it creates opportunities for different kinds of wonderful conversations with students. My conversations with students contain feedback they can use to continue developing their performances. I also build better relationships with students when I use performative approaches. Experiential learning, especially when there are opportunities for "real world" interactions, creates development in many of the same ways that a performative approach would. Experiential approaches to learning help create stages for performative approaches to learning and development.

Summary

In this chapter, you have learned the following:

What methods and approaches will the school use to train teachers to implement STEM and STEAM learning? Unfortunately, the answer is the same methods we have used for everything else! We can investigate why this is so by examining how methods and ideas for organizing classroom learning become available to teachers. For this discussion, a teaching method is a tool that can be reused to achieve a planned result or outcome. Teacher-preparation programs typically provide new teachers with many opportunities to try out different established teaching methods. The variety of teaching methods available to the profession is beyond the scope of this discussion, but it is safe to say that there is no shortage of access to methods thanks to the Internet. Teachers also benefit from professional development (PD) opportunities provided by schools and school districts. The PD provided by schools figures prominently in how new methods are integrated into teaching practices. School administrators can motivate teachers to take PD classes/seminars/training in the new methods and ideas that a school or school district has decided to budget for. The other way that teachers learn new methods is through additional state-certified professional licensing or non-degree certificate programs. I can often tell where certain school districts focus on professional development budgets by the phrases and acronyms teachers use when talking about teaching. One prominent phrase I've heard over the last 10 years is "student-centeredness."

Question

1. Who started STEM education?
2. Why is STEAM important to 21st Century education?
3. How is STEAM used in the classroom?
4. Why are STEM and STEAM important?
5. What are the principles and philosophies of STEAM education?
6. Are you familiar with the STEAM approach to education?
7. How do you get your students excited about learning?
8. Which teaching methods do you prefer?

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CHAPTER 8

SERVICE-LEARNING PROJECT

In this chapter, you will learn the following:

- **8.1 Organizing in Academia**
- **8.2 Improv Games**
- **8.3 Building an Environment with Relationships**
- **8.4 Creating New Stages**
- **8.5 Producing School**
- **8.6 Zones of Proximal Development in STEM Learning Environments**
- **8.7 Being and Becoming**
- **8.8 Performance Activism**

8.1 Organizing in Academia

I started my current appointment as an assistant professor in 2011. I was an untenured faculty member on a tenure track in my late forties, teaching teachers to use technology in the classroom. The experience of working in academia was different from the public schools and corporate environments I had worked in for most of my professional life. I had to create a new performance. Fortunately, I had plenty of life experience to draw on. My scholarship and teaching were grounded in Vygotskian cultural performative approaches to learning, but there were no other Vygotskians to be found on the faculty at my school. Recognizing this, I prioritized maintaining and developing relationships outside of my school. It was a decision that served me well. My method for navigating through my first academic year was introducing everyone I met to my “Yes, and” performance. “Yes, and” is an improvisation exercise that I play to teach people how to create a collective story. In faculty meetings, “No, but” or “Yes, but” were typical responses to new ideas and suggestions. I made it a point to offer “Yes, and” as an alternative response when my colleagues interacted with me. I playfully did this, explaining that “Yes, and” was a straightforward method for building collaborative environments. Like many new faculty members, I found academia intimidating and tended to say “yes” to suggestions to volunteer for committees or take on additional work. The amazing thing about “Yes, and” is that it creates new possibilities.

8.2 Improv Games

In my first year as a faculty member, I accepted an assignment to create a professional development program for an elementary school in Harlem. The school had U.S. Department of Education Magnet Schools Assistance program funding. The funding could be used to pay for teacher professional development. This school contacted my institution and sent me to work with them. I created a program that introduced many of the same instructional technologies I used in the graduate program I taught in. I also included improv games that I used to create new performances and ways of being in the classroom. My friend and mentor, Carrie Lobman, had written Unscripted Learning: Using Improv Activities Across the K-8 Curriculum (2009). I used many activities in the book in my professional development work. Leading strangers in improv games is not as easy as it looks, and I was encouraged that no one rejected my improvisational offers. Formal teaching observations and feedback from workshop participants were also positive and encouraging.

The professional development program with the Magnet School had me committed to one Saturday morning a month at the school for ten months and a weeklong summer institute.

Ellen Darensbourg was the school's Magnet specialist and my primary point of contact. I worked with Darensbourg to plan the workshops, train the teachers, and debrief the sessions afterward. After several months of working together, we developed a trusting working relationship that would become the foundation of our subsequent efforts in STEM (Science, Technology, Engineering, Math) education and service learning.

8.3 Building an Environment with Relationships

"Yes, and" and other improved games are methods for connecting with people, leveling the playing field, and creating an environment for new possibilities to emerge. Everyone is uncomfortable at the beginning of an improv game, and an individual's academic rank or area of expertise does not provide a competitive advantage as it might in a faculty or business meeting. Having a group experience that provides everyone with an equal opportunity to contribute to the group's efforts is a necessary preparation for developing the capacity to collaborate. The initial work with the Magnet school was considered successful by my institution; it brought non-tuition revenues to the university. I eventually managed to expand my efforts to include other Magnet schools. Darensbourg and I worked on continuing to expand our efforts together, but I was also bothered by my experience with teacher professional development. I did not see much development going on despite our best efforts.

Teachers learned to use technology and would demonstrate that they learned it, but they were not changing their classroom practices, and their attitudes toward technology use did not change. To them, the technology was an add-on, not an essential part of the classroom experience. They insisted on knowing what to do with the technology before trying to use it. They were not comfortable playing around with the technology or exploring it. They did not have the same views toward technology I knew children had. Children learn technology developmentally like they learn language; they do not have to learn about technology before using it. A few hours a month in professional development wasn't producing much developmental learning. The teachers insisted that they were uncomfortable allowing students to use technology in the classroom that they did not understand. From my perspective, the teachers unintentionally got in the way of developmental learning.

8.4 Creating New Stages

Sometimes you have to risk walking onto an empty stage when the audience invites you. Despite my efforts to create new practices for teachers using technology, they were merely learning how to use technology and sometimes applying it. One day, Darensbourg explained to me that she believed that the goal of STEM education was to teach children to think like engineers, scientists, technologists, and mathematicians. I didn't see how that would be possible, given my experience teaching teachers to use technology. I thought like a technologist, yet teachers do not think about technology or use technology the way I do. I was concerned that I'd failed to create a zone of proximal development (ZPD) where thinking like a technologist or learning developmentally was possible (Vygotsky 1978). The idea of teaching children to think like a scientist was appealing, even though I didn't believe it was possible to teach children to think like a scientist or technologists. As I saw it, a developmental approach to learning should create opportunities to engage in activities that might be developmental precursors to thinking as STEM professionals do. Children could pretend to be scientists and engineers like they pretend to be Mommy or the Teacher. They needed to interact with STEM professionals in STEM activities to learn to create those performances, just like they did at home.

I decided that I liked the challenge. I wanted to do something to create a developmental learning environment, a ZPD for interdisciplinary STEM education. Could we create an environment where learning to think like a scientist or engineer was possible in school? My STEM journey included curiosity about technology, formal training in computer science at college, extensive use of computers on my own time, and immersion in a professional technology culture. Like a technologist (and a Vygotskian), there was no way that a schooling experience could reproduce a process that had developed over 20 years or create a significant shortcut.

I learned from my work with the All Stars Project that youth development is produced on a new stage. The new stage could be an All-Stars Talent Show Network stage in a public school auditorium or a corporate boardroom down on Wall Street. I knew I needed to create stages and organize audiences for the show. That stage had to be where elementary school children could participate in shared activities with people with STEM knowledge and practices. I needed to learn how to get STEM people like scientists and engineers into an elementary school consistently and meaningfully. I am trying to remember how much time I spent mulling the idea over (it may have been a couple of months), but the answer came unexpectedly in the early spring semester of 2012.

In February, Fran, the Center for Teaching and Learning (CTL) director at NYIT, invited me to a student demonstration of a course capstone project in the School of Engineering and Computing Sciences. I was impressed by how the young engineering and computer science students presented their projects. They talked about Gantt charts, the challenges of planning their project, and the technical aspects of building technology-based solutions to problems in a collaborative environment. They sounded like the technologists and engineers I had worked with in my former career. I asked the tough questions, and I was satisfied with the answers. At that moment, a new idea occurred to me.

At the end of the presentation, I congratulated the students and asked Fran and the course instructor if it was possible to have engineering students show up at a public school to work with children. The instructor could not help me, but Fran suggested I meet with Amy Bravo. Bravo is the Director of International Education and Experiential Learning at the university. It turned out that her office was down the hall from mine, but we still needed to meet. I scheduled a meeting with Bravo and gave her a copy of my previous book as an introduction and preparation for our meeting.

It was an unusual meeting for me because it seemed that 5 minutes into explaining what I wanted to do, she stopped me and told me that the way to place students studying engineering and computer science at an elementary school was through service learning. I asked, "What's that?" The rest, as they say, is history. In Bravo, I found a fellow community organizer and an instant friend. By the time we had completed our first meeting, we were already finishing each other's sentences and planning to find a course for me to co-teach as a service-learning course in the School of Engineering and Computing Sciences. I'd discovered my stage (a service-learning course), my performers (college students, teachers, and children), and my producer (Bravo). Now we had to organize everyone to get to the show.

8.5 Producing School

Between March 2012 and September 2012, Bravo, Darensbourg, and I figured out how to bring students in the School of Engineering and Computing Sciences into elementary schools. We embedded service learning into a first-year Career Discovery course. When I imagined bringing undergraduates into elementary school, I had been thinking of juniors and seniors. Still, we were dependent on what there was to work with, not what we thought was ideal. No grant money was associated with this project. Bravo and I asked academic deans to contribute from their discretionary budgets to cover the students' travel expenses between the campus and the school. Bravo negotiated all administrative details with the School of Engineering and Computing Sciences dean. Darensbourg worked with her administration to convince them that it was a good idea for 25 college students to visit an elementary school for ten weeks. The college students would be traveling in small teams and pairs on different weekdays and scheduled to work for an hour on each visit. I convinced my academic dean that service learning would be part of my research portfolio and that I would publish the work.

The idea was that the undergraduates would arrive at the school at regularly scheduled times and participate in activities. The first-year students could participate in one of three ways: the classroom hands-on learning project teams in grades pre-K through 5, fixing and upgrading equipment on the tech team, or video recording and photographing the experience with the documentary team. The work that the college students did in school was in addition to the coursework they were expected to complete. I taught the career discovery aspect of the course during one of the two weekly sessions with the college students with my co-instructor, who taught the academic engineering content.

During class time, I created a performance that was familiar to me and one that might be useful to college students. I was a corporate technology project manager in corporate America, and that skill set would be valuable to display. I became the project manager of all the school projects the college students were working on. Darensbourg, the teachers, and the children were the clients. The college students comprised the project teams assigned to different aspects of a large-scale integration project. Each team had a project leader and various responsibilities assigned to each member, and each team had different tasks, and we were all working toward creating a public performance.

We had a large group meeting at the beginning of the semester before the students started service learning in the schools. The visit began with the teams traveling to the school and doing a neighborhood walk to get familiar with the route to the school. Darensbourg was introduced and provided an overview and history of the Magnet schools movement. Bravo asked the students to consider the civic engagement aspect of our work and asked them questions about what they observed about their new surroundings. She asked questions about creating change and creating connections to the community.

The college students signed up for project assignments and scheduled the days they would visit the schools. Darensbourg, Bravo, and I had agreed at the beginning of the semester to share our work at a community showcase event. The plan was to invite the entire elementary school—100 children, their teachers, and parents—to the event. Every week when I met with the teams in the class, we would discuss project tasks, milestones, and progress toward being ready for the Showcase Event. I had project leaders report on progress and present problems with projects and challenges to get teams to collaborate. The students felt the pressure of the new demands on them. I gave performance directions and saw new performances of collaboration, communication, and creating projects.

Darensbourg worked to track 25 college students coming and going to the elementary school every week. Service learning students visited the school three days a week, some teams in the morning and some in the afternoon. It was chaotic, but there seemed to be enough that was positive to keep everyone engaged in the project. Bravo supported the project and kept encouraging my teaching and organizing efforts during our debriefing sessions together to discuss weekly progress. We were changing everything about what it meant to learn in formal schooling settings, and it was stressful and hard to determine whether anyone was learning from week to week. Everyone was out of their comfort zones, and we (Bravo, Darensbourg, and I) had nothing but trust in each other. I also had a Vygotskian theory of human development that suggested that putting young adults in classrooms with children could produce positive things (development) if they were engaged in meaningful activities with each other.

The tech team fixed computer equipment, upgraded software, and helped teachers put it to good use. Members of that team felt it was wasteful to have so many computers in disrepair, and they were enthusiastic about getting them into service in the classrooms. The teachers figured out that they could create more group activities and use more technology with college students in the room. That provided many opportunities for the children to work with the college students in small groups with technology. Teachers noticed that the kids were more excited to be in school on the days the college students visited. The engineering majors started making suggestions about engaging in engineering activities, and the documentary group captured the enthusiasm of the school community as the changes were occurring. We would eventually discover that the changes were tangible and visible to outside observers.

On December 10, 2012, we held our Showcase Event. Four college students from our class took to the auditorium stage with two teachers. I moderated our performance of a panel discussion for 100 children, teachers, parents, faculty, deans, and the university's provost. The college students produced a 15-min-long documentary video, and we had a forty-minute panel discussion that an education reporter covered for WNYC Radio in New York City (Fertig 2012). It was the first time the teachers and the students had ever been on a panel on stage in front of an audience. It was the first time elementary school students had ever been in a college auditorium. We had produced ten weeks of school material, performing as project teams and learning about civically engaging in a public school, and everyone was happy with the results.

8.6 Zones of Proximal Development in STEM Learning Environments

“This work is messy.” That’s what Bravo says when she describes our efforts in creating new learning environments with a civic engagement learning component. The messiness is not limited to the chaos of a large project with moving parts. Many emotions are also experienced. Emotional development happens in groups that struggle at many levels (Holzman 2009, pp. 26–37). Working with people when they are struggling is “messy” compared to the highly scripted approaches to schooling, which is common when the primary task is to achieve specific learning goals. I find working with the messiness rewarding, and I grow personally and professionally.

We (our service-learning community) experienced many emotions from the beginning to the end of our project. What became apparent through the documentary video and the discussion on the panel was that although we did not understand the exact impact on the children academically, we had achieved high levels of enthusiasm for being at school and high engagement in all kinds of learning activities. One surprising result, at least for the teachers, included the children looking forward to being in school and doing project-based learning with the college students. The teachers had yet to expect to be able to utilize the undergraduates so well. They discovered that having an “extra pair of hands” in the classroom was useful. The college students assisted with small-group learning, providing individual attention to children and using more technology in the classroom. Learning activities varied from investigating the stability of structures by building with blocks, using Lego RoboticsTM, and learning to use computer-aided design software that rendered 3D images of objects.

The college students reported new respect for teachers and their hard work. They enjoyed working with the children and connecting with them on many different levels. Several college students identified with the kids personally and stated that the children reminded them of themselves at the same age. Many college students performed more service hours than were required. Some had even been able to find jobs as interns at the school after the course ended. There were many different outcomes from this work. It all happened in a messy and creative process.

We discovered that everyone experienced lots of uncertainty at the beginning of the service-learning project. Week-by-week plans laid out early in the semester unraveled because of changing school conditions and college the students' lives. We came to value the uncertainty that the project produced. People who run public schools do not typically appreciate the kinds of change that disrupt normal routines. Administrators expect the lessons to happen at a particular time of day. Students are required to internalize expectations of an orderly day and are supposed to know what the academic and behavioral expectations for them are. Schools assume that a systematic process will result in student learning.

Despite the messiness, most of our college students reported that they had grown from the experience and that the children they worked with benefited in ways they could observe. The Showcase Event, our *ensemble* performance, made our growth and development visible to audience members, including school district administrators. The Magnet school district officials were so impressed by the Showcase Event that they asked for a meeting. That meeting resulted in an invitation to scale up our project as part of the next round of Magnet grant funding to schools in Jamaica, Queens, and New York, from 2013 to 2016.

The ten weeks of service learning allowed us to create a collective experience for college students, teachers, and children. Our work together was a social and emotional experience and a cognitive experience. Teachers were surprised at the emotional impact the college students had on the children, and they explained how they were disappointed that the experience seemed to end too soon. The college students reflected on how they were taken aback by the project's demands and the immediacy of the benefit of their presence. They felt proud that they were making a difference. Darensbourg, Bravo, and I were exhausted but proud and amazed that we had pulled everything off and that it all looked so good when presented in the video and on stage. When I first proposed to the college students that there was an opportunity to be part of a panel on stage, I only had a few volunteers and had to convince the students who did participate that they could do it. Immediately after the showcase, as I congratulated students, I could hear college students who had chosen not to take part in the panel talk about how they felt they had missed out on an opportunity.

Holzman writes that "the ZPD is a dyadic relationship of assisting rather than the collective activity of creating" in most contemporary Vygotskian approaches (Holzman 2009, p. 29). We undertake the "collective activity of creating" when we do service learning in schools. The college students were not merely mentoring or tutoring the children with scripted materials. They created conversations, interacted in projects, told stories, and asked the children to talk about their lives and interests. Everyone became more creative, and they felt good about it. The college students were role models and creators of learning environments where STEM learning was happening and technology was used.

Since that first service-learning project, there have been several others, and college students consistently underestimate their impact on the school environment. They will report on how enthusiastic the elementary school students are and how ready to learn and smart they are. I remind them that the enthusiasm they have observed is what they have created with the children. It is not typically the case that elementary school children in underserved communities are eager to be in school or considered smart and ready to learn. In this zone of emotional development (Holzman 2009), building enthusiasm for being in school creates different performances for children. Those new performances also convinced college students that they were smart, ready to learn, and prepared for STEM careers. Taking pride in someone else's new performance is an emotional development for college students and professors.

8.7 Being and Becoming

I lived in a continuous state of worry while I worked on the confusion, the missed project dates, and the obstacles, and at the same time, I was confident. The college students knew that they had my support when things did not go well at school. I was becoming confident that we were creating an environment where development was happening. I felt from the weekly reports and conversations I had with the college students that learning was happening. I was confident the Showcase Event would be transformative and that we would see the transformation at the event. I was confident because I was creatively imitating a model of learning and development that I knew very well.

All Stars Project is a national youth development program with a 12-week leadership program for high school students called the Development School for Youth (DSY). In that program, adult volunteers work with inner-city high school students to create new performances that prepare them for corporate summer internships. The students, predominately Black, Hispanic, and poor, would learn a "White middle-class professional performance" from the adults. Upon completion of the program, students would perform their "graduation" in front of an audience of adult volunteers, parents, financial contributors, and internship sponsors. The program is based on Newman and Holzman's social therapeutics and the benefits of performance and creating opportunities for young people to perform. I was one of the first adults who volunteered in the program in the late 1990s. We discovered then that supporting the development of young people through performance was developmental for us (adults) as well. Having had that experience, I was very confident that positioning college students to support the development of children would promote college student development. The college student "outcomes" included the development of communication skills, empathy for others, increased awareness of societal issues impacting education, and connecting career goals to the context of civic engagement. My creative "imitation" is Vygotsky's term for what happens in a ZPD (1978, p. 87). My "imitation" of the DSY program and Newman and Holzman's approach to creating learning environments is what Holzman refers to as "a type of performance"—a "becoming," a way of taking "whom we are" and creating something new (Holzman 2009, p. 31). It is an ongoing dialectical process that is developmental and creates development.

We took college students who are STEM majors and put them in an elementary school. We created something new, and it was valued. Did the children learn anything about Science, Technology, Engineering, and Math? Have they acquired the practices of STEM majors? According to college students and teachers, children are learning the things they must teach. The children are also trying to "be" like their college mentors. The following written reflection by a Magnet school coordinator is below (summarized and edited for clarity).

Ms. H, one of the Magnet school specialists, reported that she was part of an elementary school students' conversation during a math learning session where they practiced math skills. The children talked about the college students they had met through the service-learning project. They talked about how they liked the way the undergraduate students worked with them and talked with them. They were excited to tell the college students how they were "working like machines" at their math stations. While solving their math problems, they discussed the college student's choice of study to become engineers and how they needed to do well in math if they chose the same path. While working at their math stations, the students asked Ms. H if she noticed that they were working in their groups the same way they would if the college students had been there. Ms. H was surprised and thrilled to be part of the conversation with the children.

Ms. H describes the "math talk" and creative imitation of children in the "process of being and becoming" college students. That process might not be visible to college students, but it became visible to teachers. It is also a process that cannot be measured using a standardized assessment. The standardized assessment does not capture the enthusiasm for learning math; as a matter of fact, standardized assessment tools kill enthusiasm for math.

The following is an anecdote provided by a public school administrator commenting on the impact of service learning in one of the schools in Jamaica, Queens (summarized and edited for clarity).

I will end this reflection with an experience one of our Magnet teachers shared with our evaluation team during a recent site visit to her school. She said the college students have skills, talents, and insights quite different from hers. She discussed one of her students who was having trouble in class, both academically and socially. She talked about how this little boy was a loner, was often disengaged in the classroom, and did not participate in ~~a~~ class or complete assignments. She said he did not think of himself as “smart” or “talented” in any way. She recalled how the college students worked with this child on a hands-on STEM activity. The teacher was unfamiliar with the activity. She said the college students noticed that the child had done something particularly elegant and sophisticated in this STEM activity. During the wrap-up at the end of the lesson, the college students complimented the boy and shared his work with the class, pointing out his skill and talent to the other children and her. The college students could not have known this recognition’s impact on that child, but it was profound. The teacher said—and this is what I find most moving—that she would never have recognized this child’s ability on her own because she was not very “tech-savvy” and only had a basic layperson’s understanding of the STEM activity. She was thankful that the college students had been in the classroom to recognize the little boy’s talent, encourage him, and help him see himself differently! She conveyed that this experience made her question how many other students might have talents that she is unaware of, but that might be recognized and nurtured if people had the experience and knowledge to see them. This event helped her understand more deeply the importance of exposing her students to individuals and experiences outside the classroom and the school community.

8.8 Performance Activism

Bravo, Darensbourg, and I have grown our project from one school in Harlem to three elementary schools in Jamaica, Queens, and New York. Darensbourg moved from Harlem to Queens with the Magnet funding and continues to be instrumental in coordinating our efforts in the schools. We’ve embedded service-learning into two courses in the College of Arts and Sciences that seem well suited to service learning. They are titled “Foundations of Inquiry” and “Foundations of Scientific Process,” and they work to focus college students on discovering new things about learning, community engagement, and methods of inquiry in public schools. As a result of our growth and getting funding for our partnership with the schools, we have run three concurrent service-learning courses in three schools with three different faculty members. I took on the role of researcher. Bravo continued to provide administration to the program and taught one of the courses. We both worked on recruiting and training other faculty to teach the courses. One faculty member, Lauren Rigney, has become so skilled that she has transformed her approach to teaching and assessment in the "Foundations of Scientific Process" course. In her class, there are no tests, and students provide weekly journals on their observations, "experiments" in the classroom, and "stories of discovery." Rigney teaches content from astronomy, chemistry, biology, and physics and connects that content to civic engagement in STEM learning activities.

During the focus groups I conducted in each course, college students asked me about my interests and what I expected to happen next. I tell them that I consider public schools to be places that are anti-developmental, uncreative, and in desperate need of radical change. Service learning provides an opportunity to reinitiate development in formal learning environments while still trying to achieve the goals of schools. What is clear to me is that what we can do in schools is learn to perform as scientists, engineers, technologists, or mathematicians. Children can pretend to be parents and teachers when they play among themselves. With service learning, we have created an environment where they not merely "pretend" to be scientists, engineers, and mathematicians, but they "become" scientists, engineers, and mathematicians with young adults who are in the process of becoming scientists, engineers, and mathematicians (see in this chapter).

I hope to continue to grow the project and make service-learning with public schools a permanent part of the curriculum for STEAM majors at my university and others. We have demonstrated a cultural performative approach to learning and creativity, and we have developed the capacity to organize communities of learners across cultures and institutions. Now we must be more insistent on getting increasing support for our efforts and broader participation from faculty. I hope to inspire other institutions and educators to imitate our efforts or join us in creating developmental learning environments. Based on feedback at conference presentations, we have developed a useful framework for building service-learning partnerships and creating productive and performative environments. My work in service learning was the foundation for my interest in interdisciplinary learning and the questions I started to ask.

Service learning and the challenges of creating development across disciplinary, institutional, and cultural boundaries inspired my search for a method in STEAM education.

Summary

In this chapter, you have learned the following:

In 2011, an untenured tenure-track professor taught teachers how to use technology in the classroom. Scholarship and teaching were grounded in Vygotskian cultural performative approaches to learning. "Yes, and" is an improvisation exercise that I play to teach people how to create a collective story. Fortunately, the STEAM community is just as interested in collaboration. Just like public librarians, they want to share STEAM knowledge with the community, generate enthusiasm for STEAM topics, and foster a desire to use knowledge to shape our world meaningfully. By following best practices for collaboration and focusing on shared goals, public libraries and members of the STEAM field can come together to build networks of education and encouragement that will uplift their communities and empower the public to impact their future.

Question

1. What is an example of a service-learning project?
2. What are the 5 stages of service learning?
3. What is the purpose of a service-learning project?
4. What are service-learning projects connected to?
5. What are the benefits of service learning?
6. What are the 3 types of service learning?
7. What is the importance of service learning toward community engagement?
8. What is the concept of service learning?
9. What are the characteristics of service learning?
10. How does service learning affect students?

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CHAPTER 9

REFLECTIONS

In this chapter, you will learn the following:

9.1 A Performing Approach to Developmental Interdisciplinary STEAM Learning

Throughout this book, I've presented examples of successful approaches to STEAM and STEM education initiatives. The practices and voices of interdisciplinary and innovative educators have been prominent. I've argued for creating alternatives to traditional educational approaches by showing that educators are improvising with and within the school systems they work in. They use traditional and non-traditional methods and collaborate with students and external partners. Finally, I've presented a Vygotskian cultural performative approach to creating developmental STEAM learning environments through middle school classroom and college service-learning projects. I hope that others interested in STEAM education are encouraged to be performative, playful, and creative due to reading this book.

9.2 Context

In my experience, interdisciplinary STEAM education experiences are collaborative, creative, and developmental ensemble performances. Like a child uttering her first words or taking her first steps, STEAM education ensembles struggle to make sense, contend with uncertainty, and seem awkward. The service-learning project featured in Chapter Eight started with uncertainty and felt awkward for a couple of years, but it is now an experience in learning produced by our ever-changing ensemble with great confidence. The ensemble performance of service learning is one way my colleagues and I create our method of interdisciplinary STEAM education. There are many other possibilities: the Cultivating Ensembles in STEM Education Research Conference, the Performing the World Conference, and the All Stars Talent Show Network presentations are other examples of bringing different people and communities together to produce culturally performative interdisciplinary learning experiences.

The STEAM education movement offers us opportunities to develop new attitudes about education. I framed current efforts at reform as an education for a workforce development paradigm in Part I to show what limits our attitudes about education. The paradigm is the box we are all in, and performative approaches are outside the box. Being out of the box is disorienting and entails a certain amount of risk-taking. I believe risk-taking and uncertainty must exist to create developmental learning in institutional settings. It also helps if support, coaches, champions, and teams can be organized outside the box.

It is possible to create performative experiences that break people out of our institutions' predetermined scripts. STEAM education is a new mandate to introduce creativity and innovation into education. For a short time, the STEAM education movement will be open-ended, and we will have an opportunity to explore and create educational alternatives and share them. Many of the existing tools we use for educational assessment were created to measure learning in traditional settings. We will need to build new tools to understand developmental learning in schools.

Successful STEAM education projects will have teams of people from different backgrounds who have all agreed to create a learning experience or project together. The roles people take on in interdisciplinary teams will be unclear since the projects they create will change as learning environments develop. STEAM educators will be the organizers, directors, leaders, and producers of developmental learning environments. STEAM educators will have to locate resources and expertise outside of schools and bring them into the school through physical and technological means. When bringing in resources is impossible, students and educators will go out into communities where the STEAM activities are happening.

9.3 Performance

Teaching is a performance; there is an audience, a loose script, and an opportunity to improvise. One of the "stage directions" I offer teachers is to enable student choice and participation in creating the scripted curricula in their classrooms. Responses to that direction have varied widely, but as I demonstrate to the teachers that I teach, providing students with options makes them work harder because making choices and contributing to creating the learning environment is challenging work.

Research is a performance, and interdisciplinary research is a new performance. Researchers involved in interdisciplinary collaborations spend a fair amount of time sorting out what they are doing together. The goals may sometimes be vague, and the route to the goals will need to be discovered. Communication, social and emotional skills, and openness to new ideas will be critical to cultivating ensembles in STEAM education research. Fostering playful and performative attitudes through theatrical performance and creativity exercises will be helpful to the development of interdisciplinary ensembles.

STEAM education ensembles will build communities created by different communities of practitioners coming together. Bringing together diverse groups of people who would not typically meet is, in part, made possible by twenty-first-century technologies that are now accessible to many cultures around the world. We have the technical capacity to create developmental learning environments that cross borders of every type.

STEAM education has to happen at the grassroots community level for it to be developmental and transformative. Grassroots community building is labor-intensive, socially and emotionally demanding work. Providing the leadership to create inclusive and diverse communities is an area we all need to develop.

STEAM educators do not work, create, play, or perform alone. That is the most significant finding that I can offer. STEAM educators and interdisciplinary practitioners are grassroots leaders willing to lead their students and colleagues. They succeed and fail in small ways, and they try again. They recruit peers and outsiders to their efforts, and they succeed and fail again in different ways, and their efforts eventually get noticed. They are learning how to organize people and build developmental learning environments. I've observed that STEAM educators are opportunistic; they see opportunities in breaks in the institutional routines, unique events, indifferent supervisors, and interested ones. STEAM educators are restless innovators and are unaccepting of the way things are.

STEAM educators and interdisciplinary practitioners work on reorganizing our institutions' fundamental structures or building new ones. In Chapter 4, students working with teachers transformed the use of technology in schools by contributing their knowledge and skills and creating development for themselves and others. Students working with teachers created a new structure within the institution: student-led teams that fixed technology and mentored other students.

The knowledge acquisition approach to learning in math, science, and other subjects will not likely deliver the hoped-for transformations of STEAM education. I don't see how introducing innovation and creativity into the education for a workforce development paradigm will result in developmental learning. Why would we expect that putting more reforms into the educational reform box would result in anything other than small incremental change? The search for method in STEAM education explores a new performative and transformative approach to education. I am an educational outsider and insider, and I'm encouraging a performative approach to education that is interdisciplinary and comes from outside formal education institutions. It is a methodological approach with a history of success in after-school youth development programs, community development projects, therapeutic environments, and formal educational settings. A performative approach is needed for the transformations that we would all like to see and that some of us feel are necessary to bring about educational change. The teacher-student collaborative projects and descriptions of activities and approaches to learning described in this book indicate that educators are discovering performative alternatives and that creativity and innovation are possible even within the constraints of traditional learning environments.

9.4 Play

When people hear me talk about performance and play in schools, they look at me as if I had broken a rule. On several occasions, students, colleagues, and administrators have rephrased my comments about play, adding, “They can play to learn specific things.” To be clear, I believe that children should be allowed to play in school (and maybe play school) and be encouraged to perform what they are learning. I do not believe that play needs to or can serve specific purposes in school. If the students cannot opt-out of the play activity or cannot change the activity, then whatever it is that is going on is merely masquerading as play. STEAM educators must embrace the collaborative playfulness inherent in imaginary play and art. A suggestion I can make here is one that I have benefited from: Encourage students and collaborators to participate in improvisational play, and lead the play. Afterward, have a conversation about what happened and what it felt like. I’m sure your ensemble will have discovered something new.

9.5 Imagining a TED Talk on Preparing for the Real World

There have been times in my recent career when teachers have worked with me in the classroom or read something that I wrote and then started a sentence with, “But in the real world...” I’d like to imagine a TED Talk about the real world and write a script. According to its Website (http://www.ted.com), TED is a nonpartisan nonprofit devoted to spreading ideas, usually in the form of short, powerful talks. TED began in 1984 as a conference where Technology, Entertainment, and Design converged, and today covers almost all topics, from science to business to global issues. I want to present one more creative performance before the curtain drops.

The TED Talks video starts with the familiar TED logo and audience applause. Martinez is standing on a darkened stage within the spotlight. In the background, a large screen displays a video clip from a service-learning project in STEAM education. Martinez raises his mic and addresses the audience.

Many say things like “school prepares children for real life” or “you have to go to school so you can find a job in the real world in the future.” The video you just saw is only a couple of minutes long, but it is pretty clear that we brought people together who ordinarily wouldn’t meet. In the video, college and elementary school students were engaged in STEAM learning activities and conversations. The video didn’t show preparation for a job in the real world. What you saw was the real-life practice of valuable real-world skills. When I watch the video, I see teachers, children, and community partners together, developing and learning the skills they need to transform what it means to be in school.

I think that people relate to school as not being part of the real world because there are so many things about school that don’t happen outside of school. For example, school is the only place requiring children to sit for nearly six hours daily. No parent should wish this on a child, no matter how attractive that might sound. Also, school is the only place where adults are isolated from other adults for nearly six hours a day. Again, parents at home with the kids know what that’s like and often look forward to being with other adults at the end of the day. The bottom line is that school life doesn’t feel like life outside school. Many people might think that this is the way it’s supposed to be. I don’t. I think there is an opportunity in the STEAM education movement to recreate schooling so that we can’t tell the difference between school and any other part of life in the real world. We have to create a new performance of schooling. Unfortunately, the people who run schools can’t do this by themselves. They need our support to create a new performance of schooling. I call it a cultural performative approach to developmental interdisciplinary STEAM learning. It’s a mouthful, and I don’t have a clever acronym, but we can call it a performative approach or developmental STEAM learning.

Creating developmental learning environments is something I’ve been doing in after-school and formal educational settings for the last 20 years. In these developmental environments, I’ve experienced how young people and students develop when invited to perform as leaders and learners. When I started doing this work in after-school settings, I discovered that I was studying, developing, and performing while I was supporting young people to perform and develop. The service learning work is bringing after-school development to the school day. Our service-learning college students aren’t teachers, but they are creating learning activities with children there. The college students report that they learn important things about communication, civic engagement, learning, and building relationships from interactions with children. Our teachers realize that with the extra adults in the classroom, they can take on new performances as facilitators, directors, and producers of the learning environment. Everyone is supported by someone else to do something they don't know how to do. We create developmental STEAM learning with college students volunteering for an hour a week for just ten weeks. For a child that attends school for 6 hours a day, 180 days a year, that's less than 1% of their time in school. We know that developmental learning has an impact because we've been doing it in after-school programs for decades. Now college students and teachers report that children benefit from the tiny development opportunities we create during the school day in our STEAM education projects. It's a win for college students, a win for teachers, and a win for children. Imagine what students and teachers might be able to do if we increased the number of hours of developmental learning with community partners in schools to 5% or even 10%.

Service-learning and afterschool programs aren't the only ways to create developmental STEAM learning environments. Teachers who have become invested in bringing STEAM education to schools have discovered that their students are great collaborators when they contribute as leaders and experts at school. I've seen how teachers have organized students who wanted to volunteer to become members of technical support teams and peer mentoring groups. These teachers have been creative, playful, and performative in building relationships that create interdisciplinary STEAM education. They've been creative in spotting opportunities to change the way things are. They've been playful in acknowledging that they need help from others and that it doesn't mean they have failed at something. They are performative when they perform as leaders and support leadership in others. The STEAM education movement has allowed us to build new stages for new performances at school.

What does it take to get up on a stage and perform? Performing for an audience can be a very scary proposition. It takes preparation, practice, and a willingness to be playful in front of an audience. Those are the same things any good teacher can do. I encourage you to go out and find your STEAM ensemble or team and create your performance of interdisciplinary STEAM development. The good news is that many other educators, artists, and performers can help. I've even written a book that can help you get started.

Some might challenge your efforts at playing, performing, or making a fun STEAM project in a formal educational setting. They might ask how playing and performing will translate into preparing students to compete for jobs in the real world. You might say that students who develop the ability to collaborate, see old problems from new perspectives, and lead others in efforts to solve complex interdisciplinary problems won't need to compete. They are busy transforming the world right now.

Summary

In this chapter, you have learned the following:

Program evaluation is nothing new for public libraries. Attention to this aspect of library work has only grown in recent years as libraries, and all public entities have been under pressure to justify their value in the face of shrinking or stagnant budgets. Still, a focus on teaching and learning can greatly expand our understanding of the purpose and process of evaluation. It can generate new data that makes a compelling case for our services and resources. In this chapter, we will explore how assessment and evaluation methods from informal and formal education environments can be effectively applied to STEAM learning experiences in the public library.

Question

1. What are program evaluation questions?
2. When should program evaluation begin?
3. What are the three main questions program evaluation can answer?
4. What are examples of program evaluation?
5. How do you write an evaluation question?
6. What is the main goal of program evaluation?
7. What is the purpose of program evaluation?
8. What are program evaluation methods?
9. What is the process of program evaluation?
10. What is the concept of program evaluation?

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CHAPTER 10

GETTING STARTED WITH ARDUINO

In this chapter, you will learn the following:

10.1 What is Arduino?

10.2 What Can You Do With Arduino?

10.3 Preparations to Using Arduino

10.4 Explore Arduino Boards

10.5 Using Arduino with Sensor and Actuator

Chapter 10– Getting Started with Arduino

Learning Goal: After understanding what an Arduino is and what preparations are needed to operate the Arduino, learn the composition of the Arduino board.

10.1 What is Arduino?

Key Point *Arduino is a small computer with a micro-computer that can input (sensor) and output (control).*

Arduino was designed at IDII (Interaction Design Institute) in Italy in 2005 to allow students unfamiliar with hardware to control their design work easily.

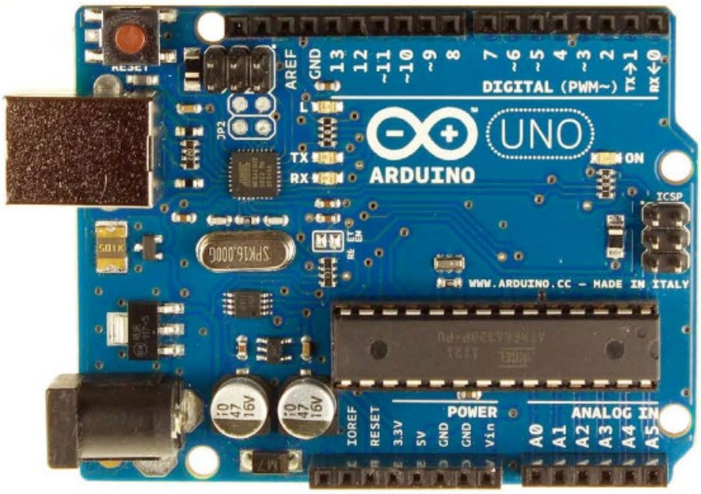


Figure 10.1 Arduino Board

Since the circuit Arduino is open source, anyone can make and modify the board directly. Arduino can create objects interacting with the environment by receiving input values from various switches or sensors and controlling the output with electronic devices such as LEDs and motors. For example, various products such as simple robots, thermo-hygrometers, motion sensors, music and sound devices, smart home implementation, infant toys, and robot education programs can be developed based on Arduino. Arduino receives various inputs from switches or sensors as follows:

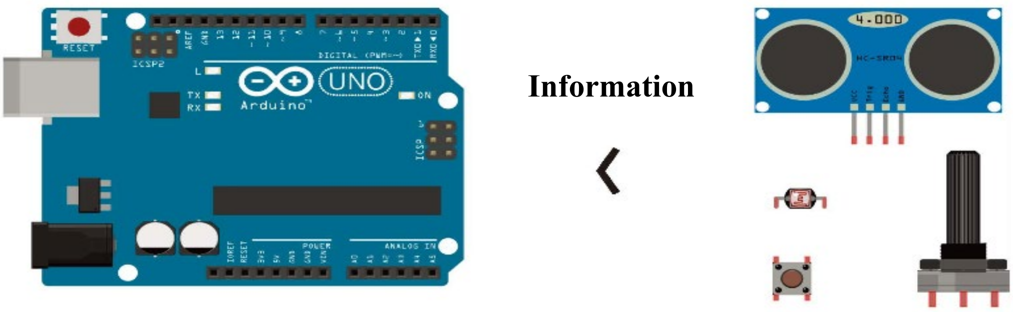


Figure 10.2 Arduino Input Devices

In addition, Arduino outputs various outputs such as LEDs or buzzers as follows:

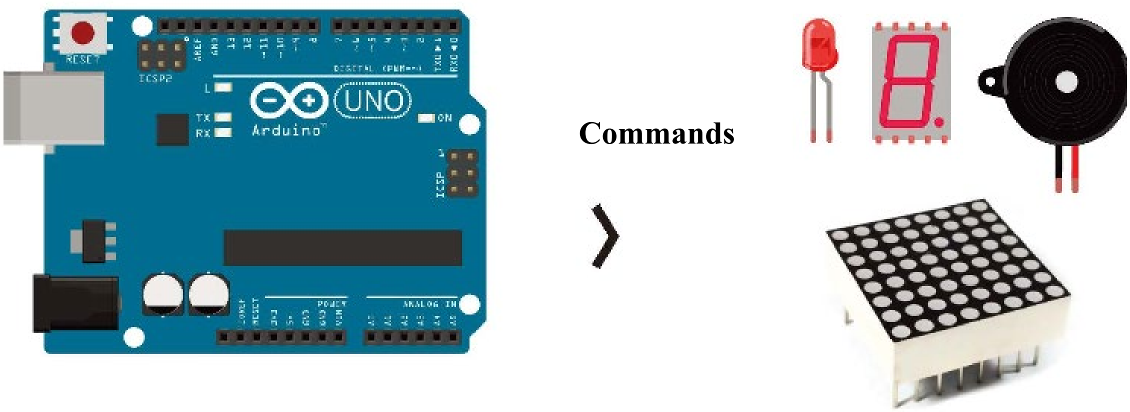
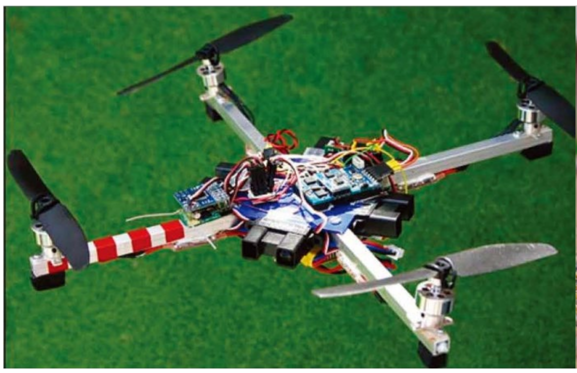
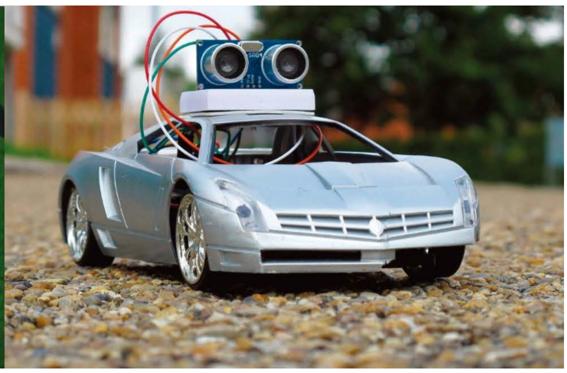


Figure 10.3 Arduino Output Devices

10.2 What Can You Do With Arduino?

Using Arduino, we can make many things we can imagine. After connecting the Arduino to the computer, you can write commands (codes) and upload them to the memory to control various devices, such as sensors and motors connected to the board. For example, you can create a system that controls a greenhouse by connecting a temperature sensor and a motor. If the temperature rises above a certain level to grow crops in the greenhouse, you can request a text message to lower the temperature or have the greenhouse open automatically. If the temperature is the desired one, you can send a text message saying it is normal. It is also possible to make robots necessary for real life. For example, it is possible to create various devices or appliances that can be used in real life, such as a robot vacuum cleaner, a device that feeds pets at a set time, and a device that automatically opens and closes curtains on a balcony or living room depending on the amount of light. These devices do not require advanced knowledge of hardware, and even ordinary people can make their own devices with a little study of Arduino.





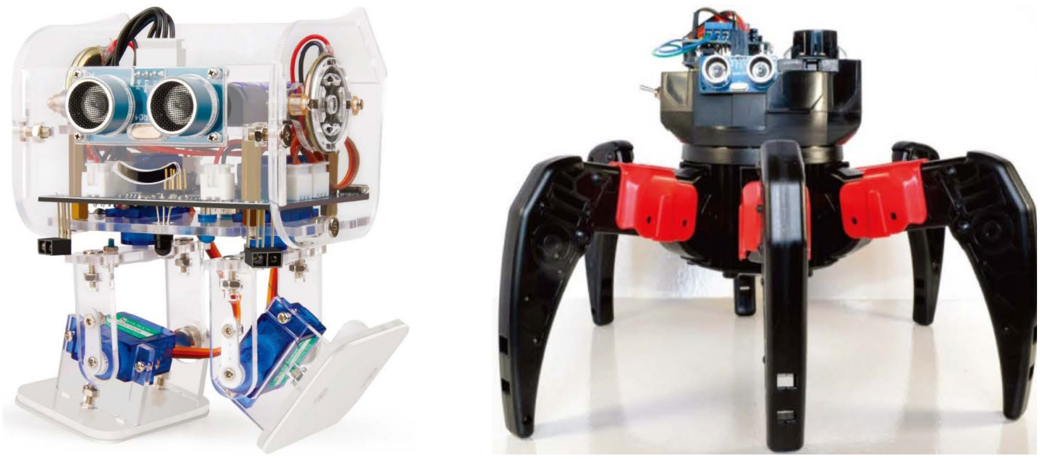


Figure 10.4 Robots Projects Make by Arduino

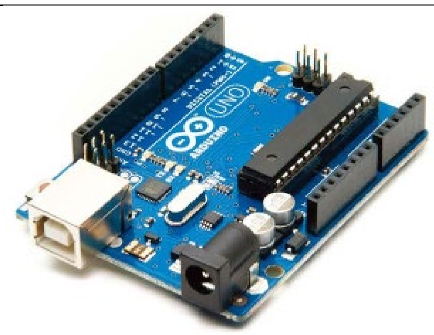
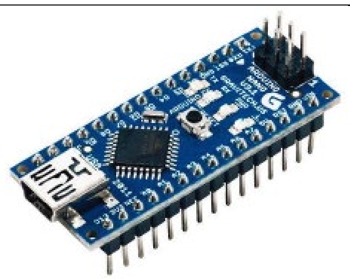
10.3 Preparations to Using Arduino

To use Arduino, an Arduino board, Arduino software, breadboard, jump wire, and other sensor parts must be prepared.

10.3.1 Arduino Board

Key Point *Arduino boards is an open-source electronics platform based on easy-to-use hardware and software.*

Since Arduino is an open-source platform with an open hardware structure, there are various kinds of official boards and numerous boards compatible with the official boards. The representative official Arduino board types, are as follows.

	**Arduino Uno** - Most used basic Arduino board. - 8-bit atmega328p microcomputer is used - The pin arrangement of the board is used as standard.
	**Arduino Nano** - It has almost the same configuration as the Arduino Uno board and is much smaller than the Uno board.

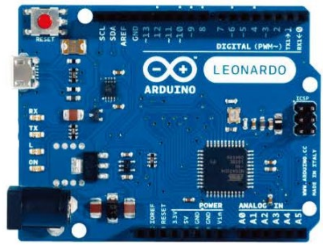
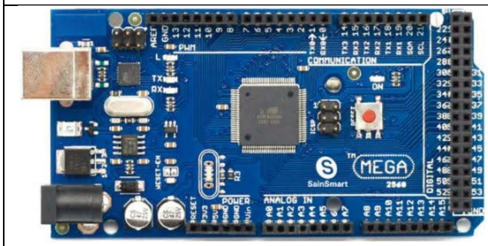
	**Arduino Leonardo** - Use an 8-bit Atmega32u4 microcomputer with a built-in USB function. - Two hardware serial ports are available.
	**Arduino Mega** - 8bit Atmega2560 microcomputer is used. - It has more functions and more pins than the Uno board.

Figure 10.5 Types of Arduino Board

10.3.2 Arduino Software

Arduino software can be downloaded from the official Arduino website. Supported operating systems are Windows, Mac OS X, and Linux, and you can download the software appropriate for the operating system you are using on your system. After compiling and writing the source in Arduino sketch, Arduino software can be uploaded to the Arduino board, and the result can be checked through the board.

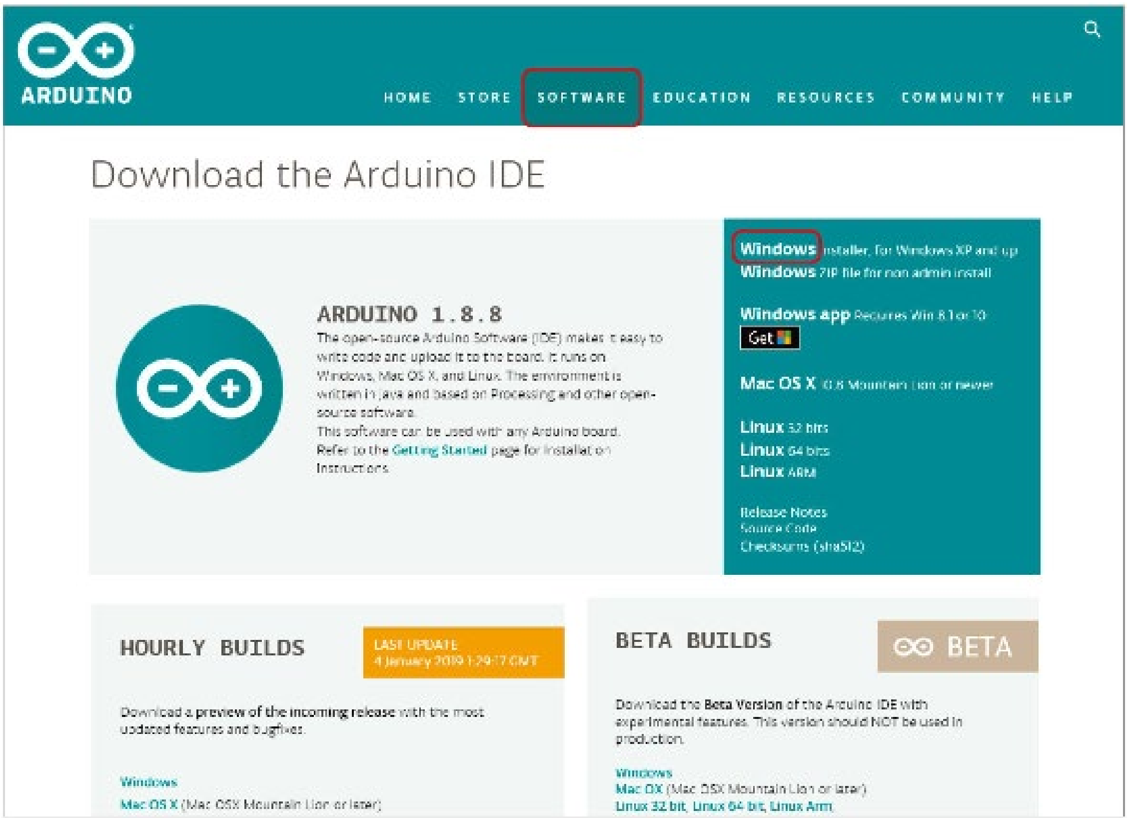


Figure 10.6 Site for Downloading Arduino Software

10.3.3 USB Cable

The following USB cable is required to connect the Arduino board to the PC.

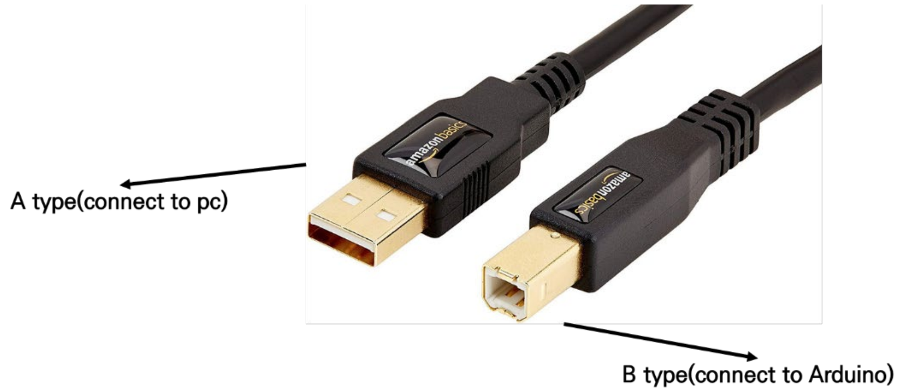


Figure 10.7 Arduino USB Cable

This cable is a USB 2.0 A(M) to B(M) cable. The Arduino board receives power and communication with the computer using a USB cable.

10.4 Explore Arduino Boards

The Arduino board consists of 14 digital input/output pins, six analog input pins, power (5V, GND), status LED (L, TX, RX), and a reset button. Power can be supplied by USB port and DC power.

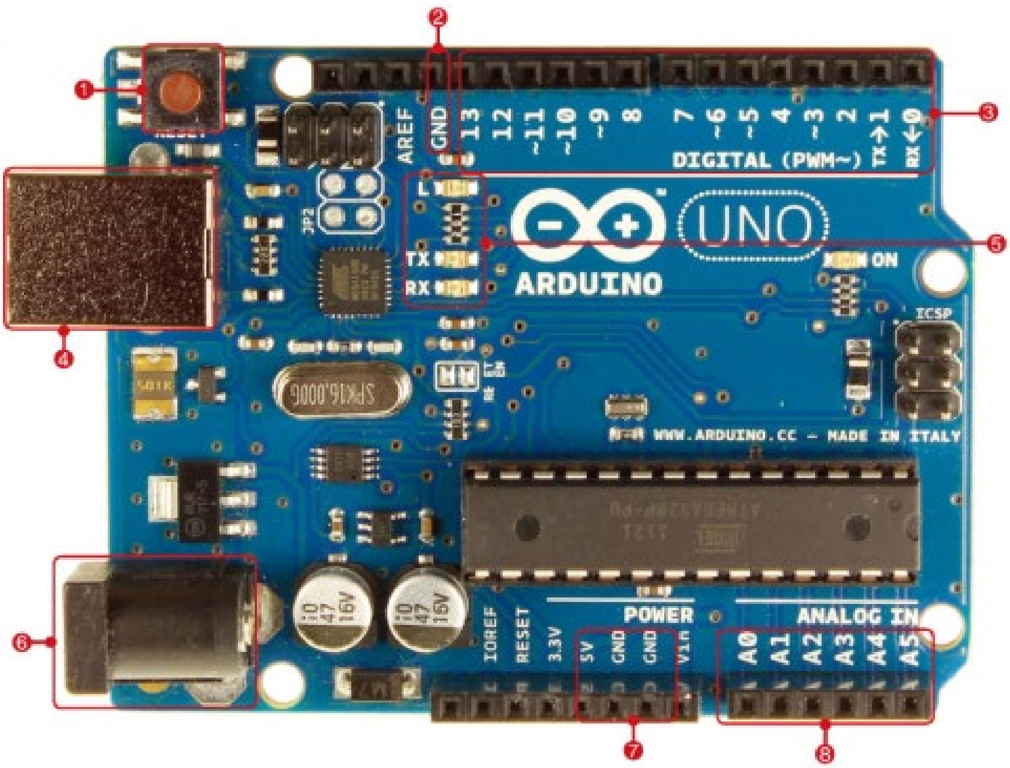


Figure 10.8 Arduino Board Description

❶ Reset Button

❷ Power (GND)

❸ Digital I/O Pins

❹ USB Connector

❺ Status LED

❻ DC Power Connector

❼ Power (5V, GND)

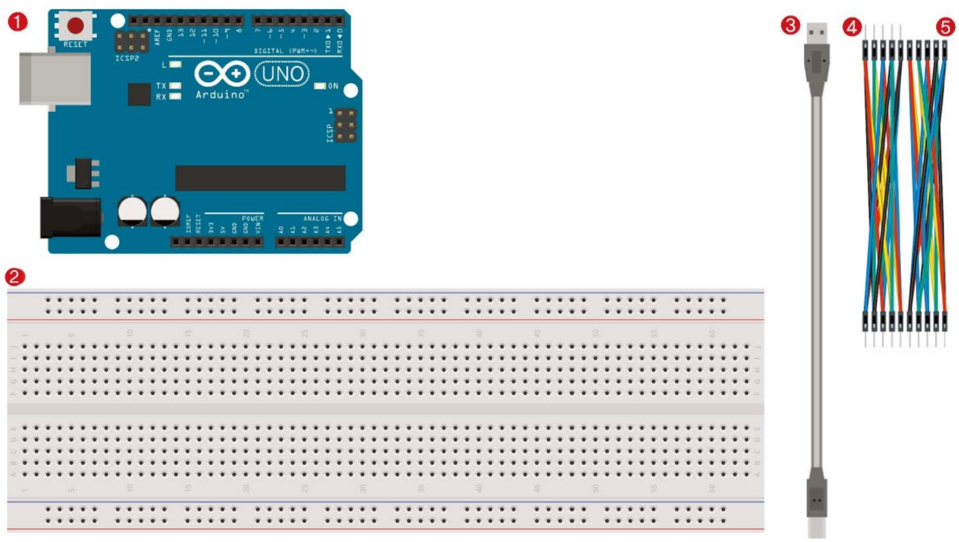
❽ Analog Input Pins

The digital input/output pin plays the role of receiving 0V or 5V values internally or externally. The analog input pin receives an analog input value from the outside and connects it with the sensor. The analog input value is read by dividing the voltage value between 0 and 5V into 256 steps.

10.5 Using Arduino with Sensor and Actuator

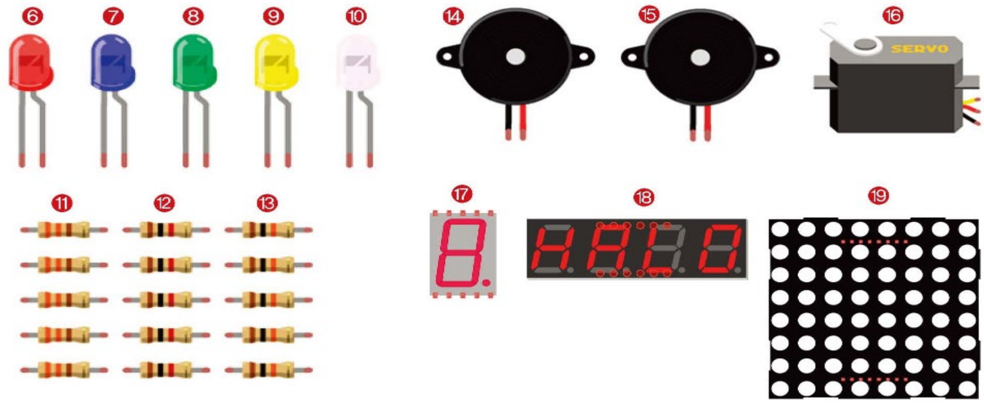
Used for Arduino, and it is essential to use various sensors and actuators.

10.5.1 Breadboard and a Jumper Wire

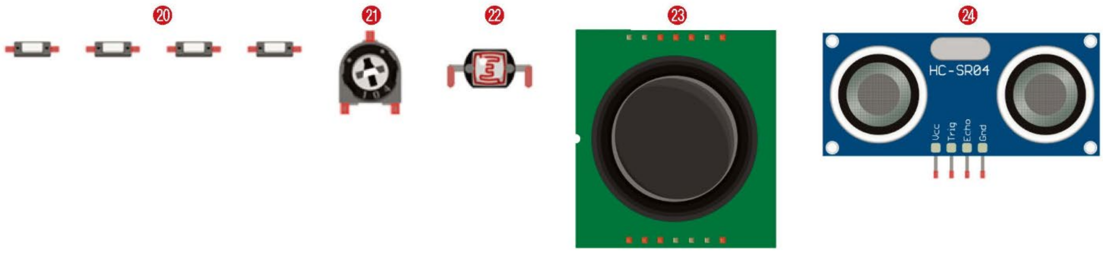


❶ Arduino Uno❷ Breadboard ❸ USB cable ❹ Jumper Wire (M to M) ❺ Jumper Wire (M to F)

10.5.2 Arduino Output: Actuator



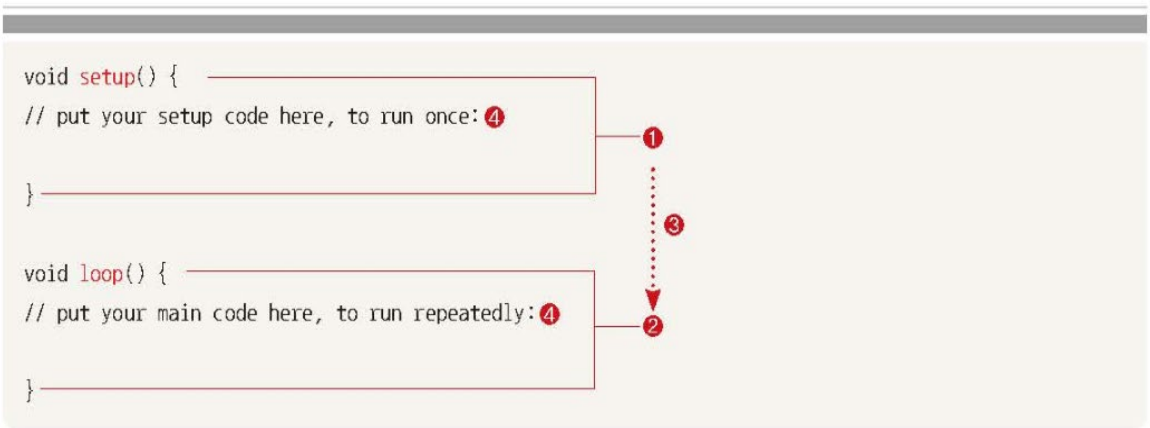
6~10. LED, 14~15. Piezo Buzzer, 16. Servo Motor, 17. Seven Segments, 18. Four Seven Segments, 19. Dot Matrix



20. Push Button 21. Variable Resistance 22. CDS 23. Joystick 24. Ultrasonic Sensor

10.6 Start Arduino Sketch

Arduino Sketch is based on the C/C++ language. These languages start with a 'main' function. Arduino sketch consists of two basic functions, 'setup' and 'loop'.



❶ The setup function is executed only once when the code starts executing. This is the operation to initialize the hardware (sensor, motor, etc.) to be used. All functions start with { and end with }.

❷ The 'loop' function is repeatedly executed and is a working that repeatedly operates hardware.

❸ When the Arduino board is powered on, the setup() function is executed once, and the loop function is repeated infinitely.

❹ // stands for program description and comments, and it is a part of memos and explanations about the code regardless of program execution.

CHAPTER 11

ARDUINO'S BASIC SKILLS

In this chapter, you will learn the following:

11.1 The digitalWrite Function

When controlling LEDs using an Arduino sketch, we usually use the following three functions:

```
pinMode(pin, mode)
digitalWrite(pin, value)
delay(ms)
```

PinMode Function

The pinMode() function configures a pin as either an input or an output.

```
pinMode(pin, mode);
```

❶ The pin number to set ❷ The mode to set., INPUT or **OUTPUT**

To use the pinMode() function, you pass the pin number to configure and the constant INPUT or OUTPUT. You can use the pin numbers from 2 to 13. You also can use Analog 0 to 5 and number those from 14 to 19. There are three kinds of modes, INPUT, OUTPUT, and INPUT_PULLUP. Turning on a LED is an output. Therefore you use the OUTPUT, whereas you use the INPUT when using the input of the Button. In the case of the Arduino internal resistance, we use INPUT_PULLUP.

digitalWrite Function

The digitalWrite() function outputs a value on a pin. It sets a pin as HIGH or LOW.

```
digitalWrite(pin, value);
```

❶ The pin number to control ❷ HIGH or LOW

The digitalWrite function uses HIGH(=1) and LOW(=0) values as digital pins. In the case of HIGH, the corresponding pin is set to 5V, and in the case of LOW, it is set to 0V pin.

Delay Function

The delay function stops progressing the program by the time of the factor.

```
delay(ms);
```

❶ Milliseconds to stop(ms)

11.2 Turn Arduino LED On and Off

① Turn on the LED connected to the 13th pin of Arduino Uno. The Arduino pin 13 is connected to an LED marked L on the board.

```
const int LED = 13;

void setup() {
 pinMode(LED, OUTPUT);

 digitalWrite(LED, HIGH);
}

void loop() {


}
```

② Select the Tools menu and select Ports as follows (depending on your computer).

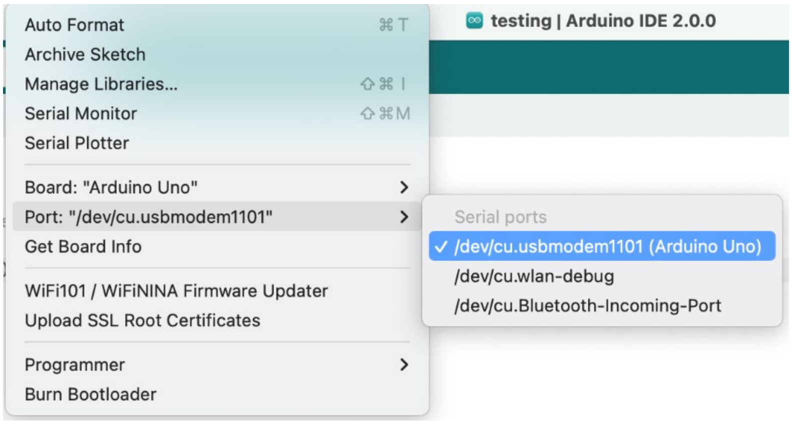


Figure 11.1 Select Arduino Port

③ Compile and upload

④ When the message "Uploading completed" appears in the message area, check if it is on the main LED next to pin 13 of the Arduino.

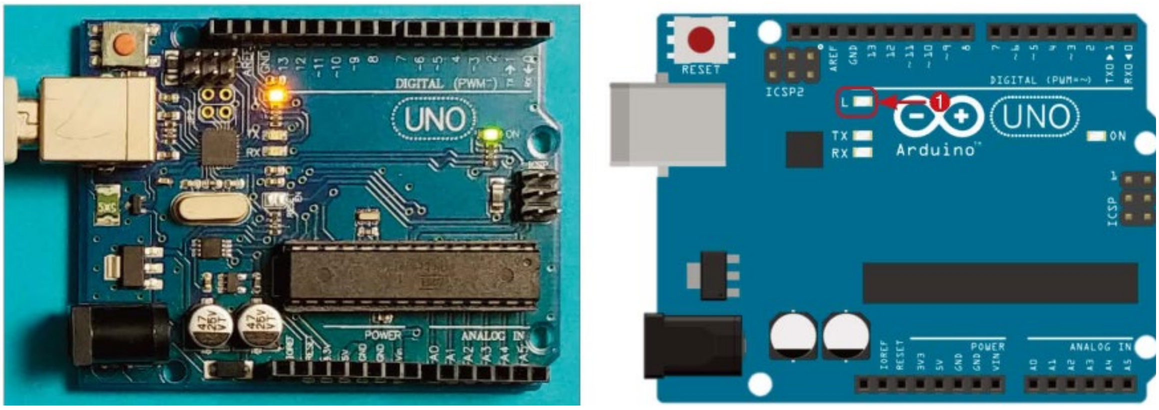


Figure 11.2 Arduino Output

The method to turn off the LED using the digitalWrite() function is as follows: Input LOW value to LED of digitalWrite().

```
const int LED = 13;
void setup() {
  pinMode(LED, OUTPUT);

  digitalWrite(LED, LOW);
}
void loop() {
}
```

11.3 Arduino LED Turn On and Off the Loop

Turning the LED on and off repeatedly using the digitalWrite function:

```
const int LED = 13;

void setup() {
  pinMode(LED, OUTPUT);
}

void loop() {
  digitalWrite(LED, HIGH);
  delay(50);
  digitalWrite(LED, LOW);
  delay(50);
}
```

In the case of the above example, it blinks 100 times per second because it is repeatedly turned on and off every 50ms.

11.4 Understanding the Breadboard

The Breadboard combines the English words ‘Bread’ and ‘Board’. ~~The~~ Breadboards are devices that are used to make prototypes of electronic circuits. They do not require soldering and can be reused. The breadboard varies in size and type. The most popular breadboard is a 400-hole breadboard. It is about half the size of an adult’s palm, and this 400-hole breadboard is enough for the following learning material.

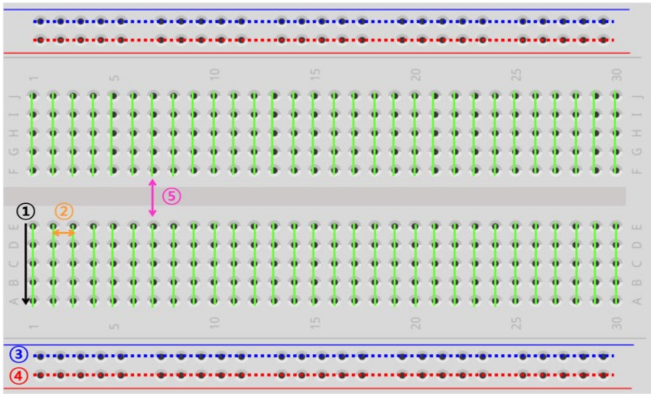


Figure 11.3 Breadboard Arduino

First, the green lines of the breadboard have five holes connected in the vertical direction. Five holes are vertically connected if you look at ①’s black arrow. However, ②’s horizontal holes are not connected. ③’s blue line and ④’s red line are connected to all holes in a straight long horizontal axis. However, the holes in the red and blue lines are not connected. The part ⑤ is not connected to the upper and lower parts.

11.5 Controlling LEDs with Arduino

Now, we will control the LED’s power by outputting a HIGH(1) or LOW(0) signal through a digital pin of the Arduino.

Parts Required

Figure 11.4 Uno Board / Breadboard / Jumper Wire / LEDs / 220 ohms(Ω)

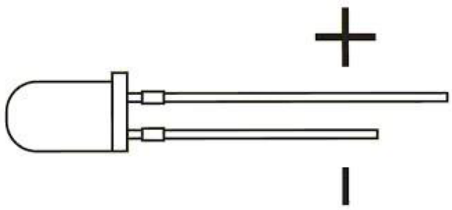


Figure 11.5 The Polarity of LED: Long Side is Anode(+), the Short Side is Cathode(-)

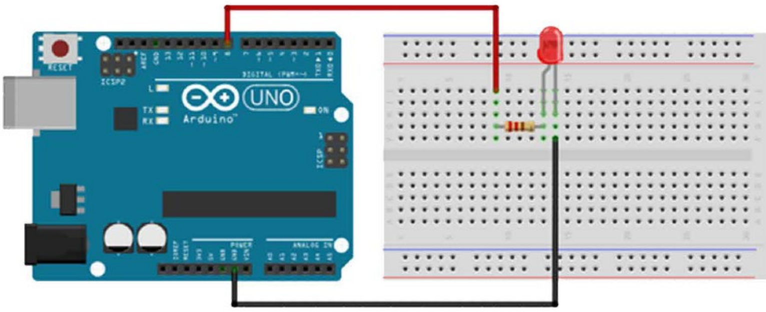


Figure 11.6 Structure of LED Light

Connect the LED's (-) pole to the Arduino GND.

Connect the (+) pole of the LED to the digital pin 8 of the Arduino.

(Connect with a 220-ohm resistor in the middle.)

```
void setup() {
  pinMode(8, OUTPUT); // Set digital pin 8 as output mode.
}

void loop() {
  digitalWrite(8, HIGH); // Output the HIGH signal (5V) to pin 8.
  delay(1000); // hold for 1 second
  digitalWrite(8, LOW); // Output the LOW signal (0V) to pin 8.
  delay(1000);  // hold for 1 second.
}
```

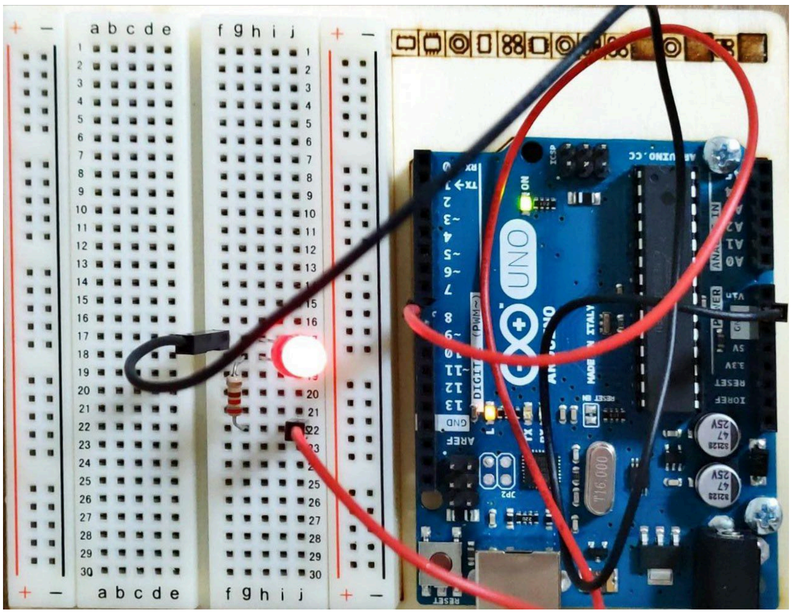


Figure 11.7 Demo on Real Arduino Board

After setting the digital pin 8 to which the LED is connected as the output mode, the power of the LED is repeatedly turned on and off by outputting a HIGH (5V) signal for 1 second and a LOW (0V) signal for 1 second.

※ Advanced Learning 1

Make a blinking LED using two or more LEDs.

※ Advanced Learning 2

Let's make a traffic light using 3 LEDs and a resistor. Red is 5 seconds, yellow is 1 second, and green is 5 seconds.

Parts Required: Uno R3, USB cable, Breadboard, red, yellow-green LED, 220Ω resistor (3 pcs), Jumper wire.

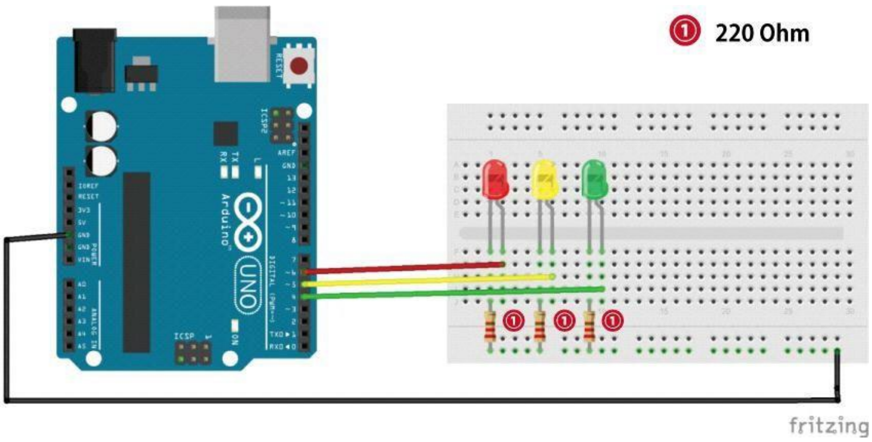


Figure 11.8 Structure of Traffic Light Project

```
int REDpin = 6;
int YELLOWpin = 5;
int GREENpin = 4;

void setup()
{
  pinMode(REDpin, OUTPUT);
  pinMode(YELLOWpin, OUTPUT);
  pinMode(GREENpin, OUTPUT);
}

void loop()
{
  digitalWrite(REDpin, HIGH);
  delay(5000);
  digitalWrite(REDpin, LOW);
  digitalWrite(YELLOWpin, HIGH);
  delay(1000);
  digitalWrite(YELLOWpin, LOW);
  digitalWrite(GREENpin, HIGH);
  delay(5000);
  digitalWrite(GREENpin, LOW);
}
```

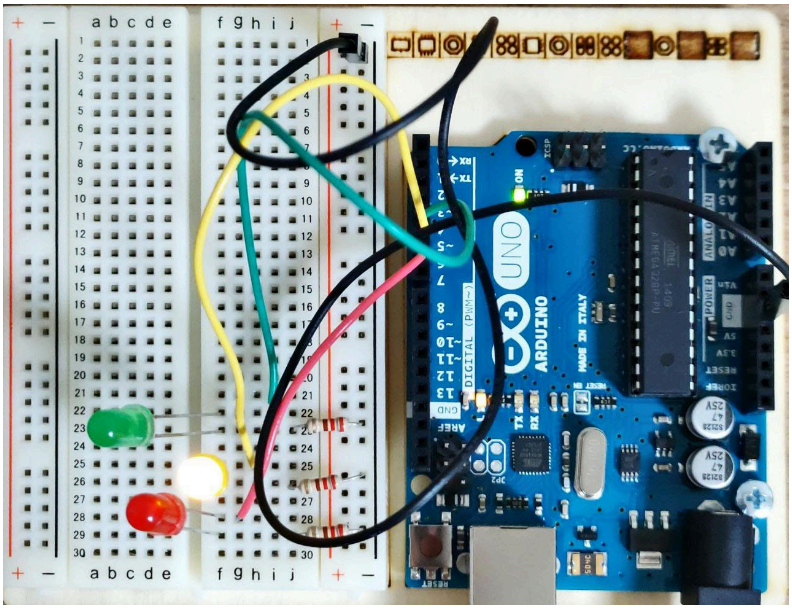


Figure 11.9 Output Traffic Light Using 3 LEDs

※ Advanced learning - Constructing Complex LED Circuits

After connecting 8 LEDs in a line, create an array to operate the LEDs efficiently.

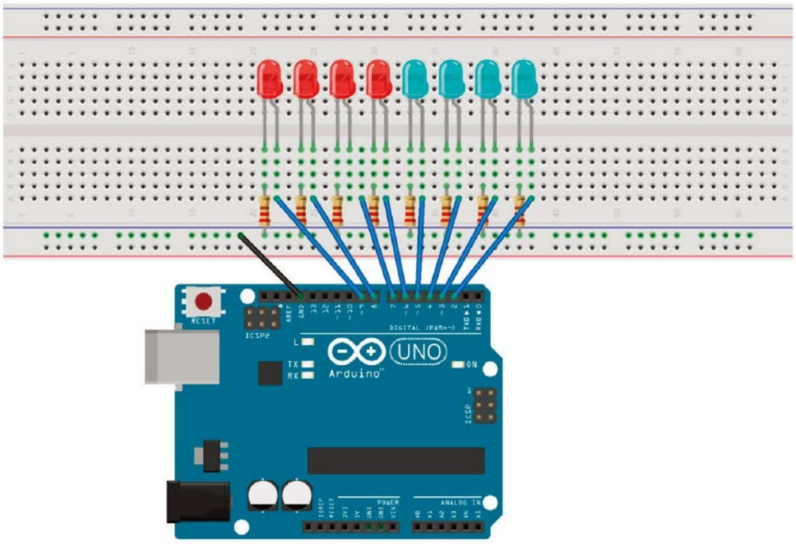


Figure 11.10 Structure of Connecting 8 LEDs Light

8 LEDs are arranged as shown in the figure above. A resistor connects each LED’s cathode (-) to GND. Connect the 8 LED anodes to pins 2~9 of the Arduino board in order from the left with wires.

1) Turn on all LEDs

The code is as follows:

```
const unsigned int led_0 = 2;
const unsigned int led_1 = 3;
const unsigned int led_2 = 4;
const unsigned int led_3 = 5;
const unsigned int led_4 = 6;
const unsigned int led_5 = 7;
const unsigned int led_6 = 8;
const unsigned int led_7 = 9;

void setup() {
 // led initialization
  pinMode(led_0, OUTPUT);
  pinMode(led_1, OUTPUT);
  pinMode(led_2, OUTPUT);
  pinMode(led_3, OUTPUT);
  pinMode(led_4, OUTPUT);
  pinMode(led_5, OUTPUT);
  pinMode(led_6, OUTPUT);
  pinMode(led_7, OUTPUT);

  // turn on the led
  digitalWrite(led_0, HIGH);
  digitalWrite(led_1, HIGH);
  digitalWrite(led_2, HIGH);
  digitalWrite(led_3, HIGH);
  digitalWrite(led_4, HIGH);
  digitalWrite(led_5, HIGH);
  digitalWrite(led_6, HIGH);
  digitalWrite(led_7, HIGH);
}

void loop() {

}
```

Second, check that all of the eight LEDs are turned on as follows:

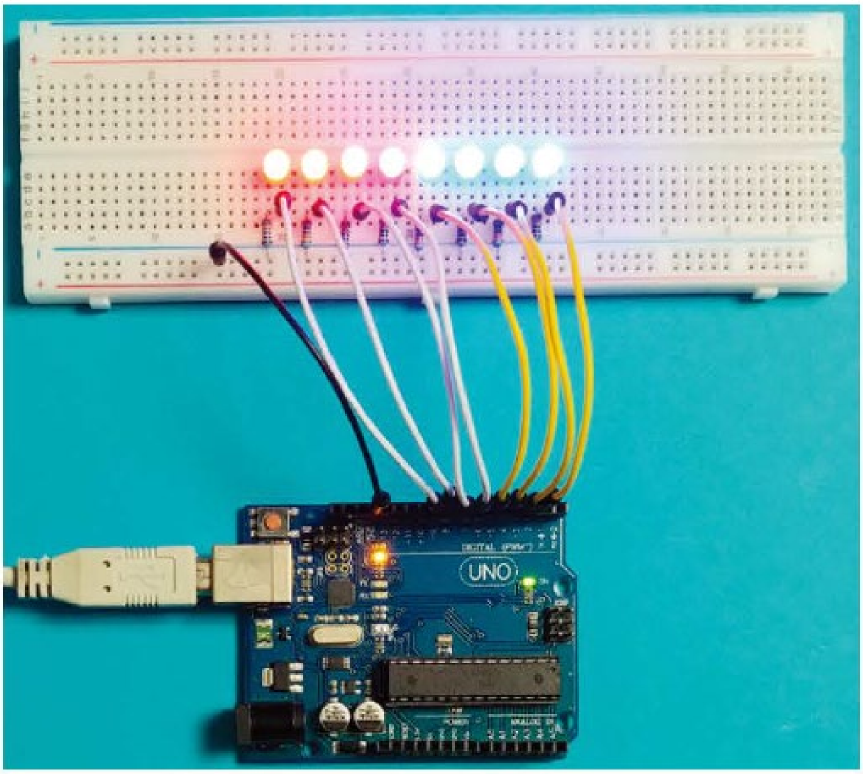


Figure 11.11 Output Connecting 8 LEDs

2) Turn the LEDs on and off in turn

Now, let's repeat the eight LEDs on and off in sequence. If you reduce the on-off time interval, you can make all eight LEDs appear to be on at the same time. Modify the example to turn on all the LEDs as in the following code:

```
const unsigned int led[8] = { 2, 3, 4, 5, 6, 7, 8, 9 };

void setup() {
  for(int x=0;x<=7;x++) {
    pinMode(led[x], OUTPUT);
  }
}

void loop() {
  for(int x=0;x<=7;x++) {

 // turn off all LEDs
  for(int x=0;x<=7;x++) {
    digitalWrite(led[x], LOW);
  }

  digitalWrite(led[x], HIGH);

  delay(1);//1/4=0.25Hz
  }
}
```

It takes 0.5 seconds to turn on and off one LED and 4 seconds to turn on and off eight LEDs one at a time. Make sure you get a result like the pictures below:

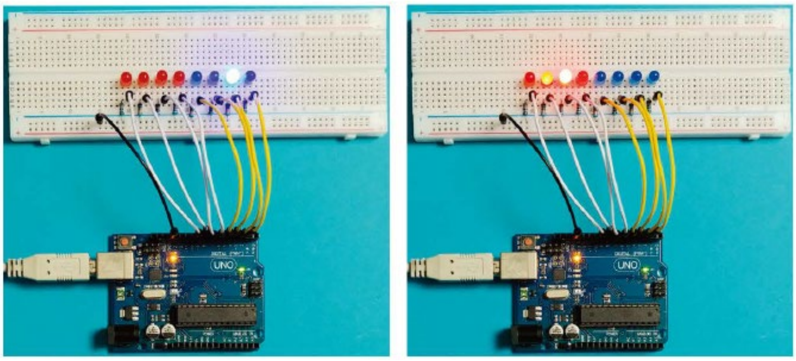


Figure 11.12 Output Connecting 8 LEDs with Turn On and Off

Modify line 19 as follows:

```
delay(5); //100/4=25Hz
```

The eight LEDs turn on and off in turn at 0.005-second intervals, but they are so fast that you can’t see them properly, and so it seems like the entire LED is waving.

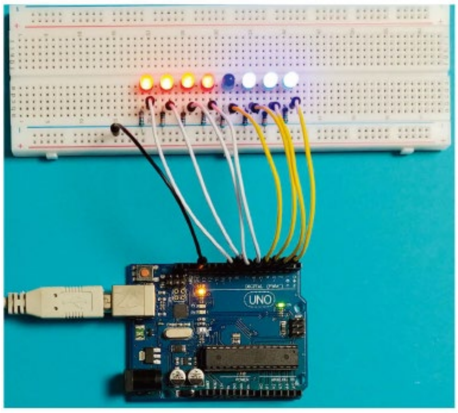


Figure 11.13 Output Connecting 8 LEDs by time intervals

11.6 Control the LED with the Switch Button

1) Turn on LED using the Push Input Button

Parts Required: Uno R3, USB cable, Push Button, 10K resistor, red LED, 220Ω resistor, Jumper Wire.

Figure 11.14 Switch Button

When you want to turn the LED on or off using a button, use the digitalRead function to know whether the button is pressed or released.

When the push button is open (not pressed), there is no connection between the two legs of the button. Without a pull-down resistor, the logical value of the pin is very vague. A 10K resistor is used as a pull-down resistor to ensure that the Arduino pin is a LOW signal. The pull-up resistor will keep it HIGH and go LOW when the button is pressed.

The following pins can read 1, 0 through the digitalRead function.

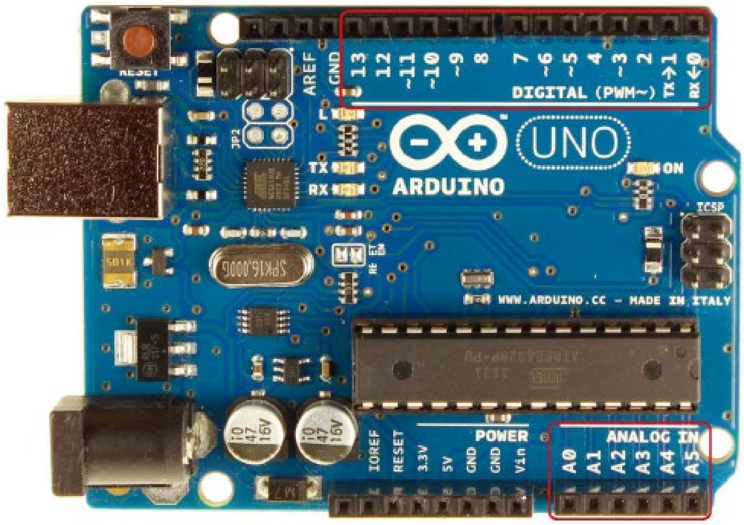


Figure 2.14 Digital Pins Able to Read 1 and 0 Through the digitalRead Function

You need to use the following two functions when you want to know whether a button is pressed or released through an Arduino sketch:

1. pinMode(pin, mode) 2. digitalRead(pin)

digitalRead is a command to read the value of a specific pin.

```
digitalRead(pin);
```
❶

❶ Returns the HIGH or LOW value of the pin number to be read.

The digitalRead function is a function that logically reads 1, 0 depending on the state of the allocated pin connected to VCC (=5V) or GND. When the assigned pin is connected to VCC (=5V), it reads 1, and when connected to GND, it reads 0.

Configure the circuit for the button circuit input and LED output as follows.

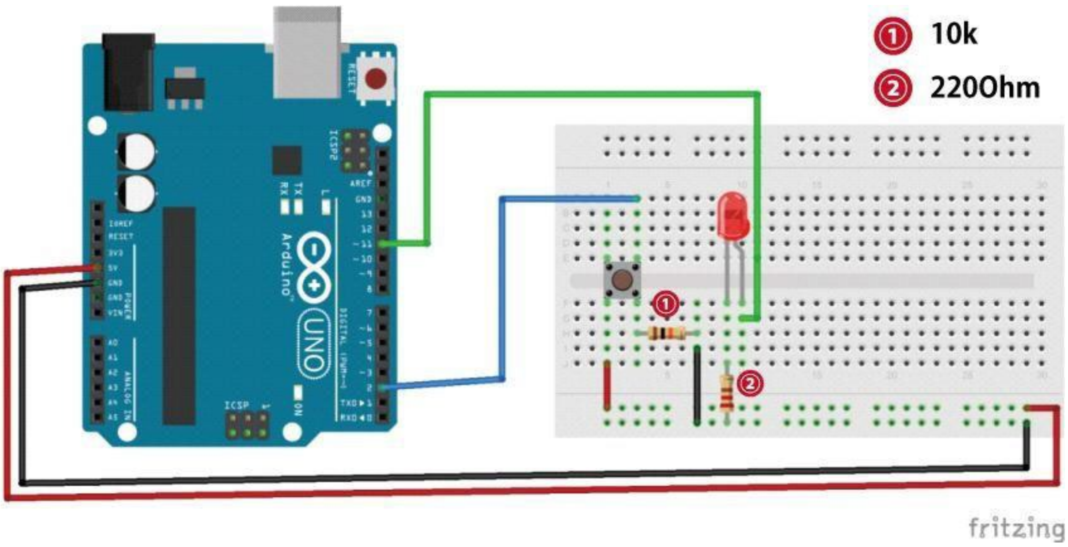


Figure 11.15 Structure Switch LED Turn On/Off Using Switch Button

```
int buttonpin = 2;
int LED = 11;

void setup() {
  pinMode(buttonpin, INPUT);
  pinMode(LED, OUTPUT);
}

void loop() {
  int buttoninput = digitalRead(buttonpin);
  if (buttoninput == 1)
  {
    digitalWrite(LED, HIGH);
  }
  else
  {
    digitalWrite(LED, LOW);
  }
}
```

Result: The LED will be on when the pushbutton is pressed and off when not.

※ Advanced Learning 1: Adjust the LED brightness according to the button's value.

Write a program so that the brightness of LED 10 changes when the button is pressed, and the LED turns off when the button is released.

First, configure the circuit as follows:

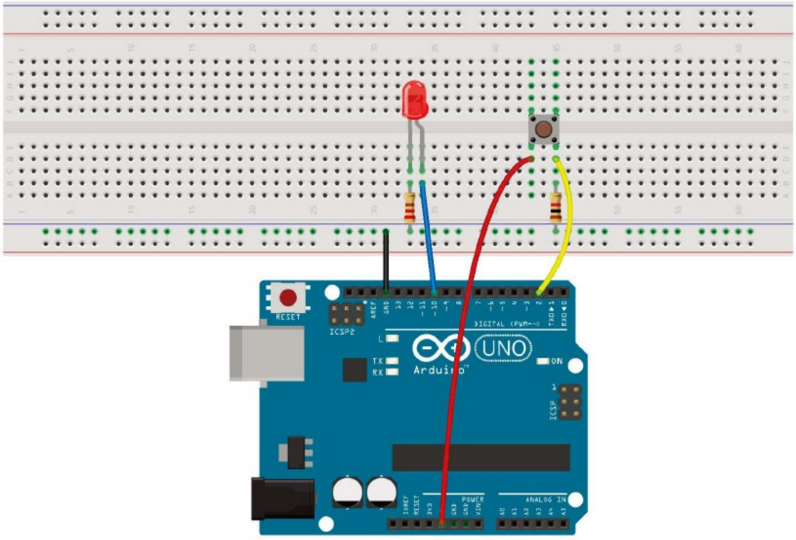


Figure 11.16 Structure Adjusting LED Brightness by Value Switch Button

Connect the LED's long pin (+) to pin 10 of the Arduino board. The LED's short pin (-) connects to the GND pin through a 220Ω or 330Ω resistor. Connect one pin of the button to 5V (red wire). The other pin of the button is connected to GND through a 1KΩ resistor (black wire). Connect the other pin of the resistor to pin 2.

```
const int ledPin =  10;
const int buttonPin = 2;

void setup() {
  pinMode(buttonPin, INPUT);
}

void loop() {
  int buttonInput = digitalRead(buttonPin);
  if(buttonInput == HIGH) {
  for(int t_high=0;t_high<=255;t_high++) {
    analogWrite(ledPin, t_high); //t_high value is changed periodically from 0 to 255
 delay(4);  // 4 milliseconds delay
  }
  } else {
  analogWrite(ledPin, 0);
  }
}
```

※ Advanced Learning 2: Making LED Dice

Write a program so that when the button is pressed, 6 LEDs are turned on at a fast speed, and when the button is released, only the LEDs are turned on. The position value of the lit LED becomes the dice value. First, configure the circuit as follows:

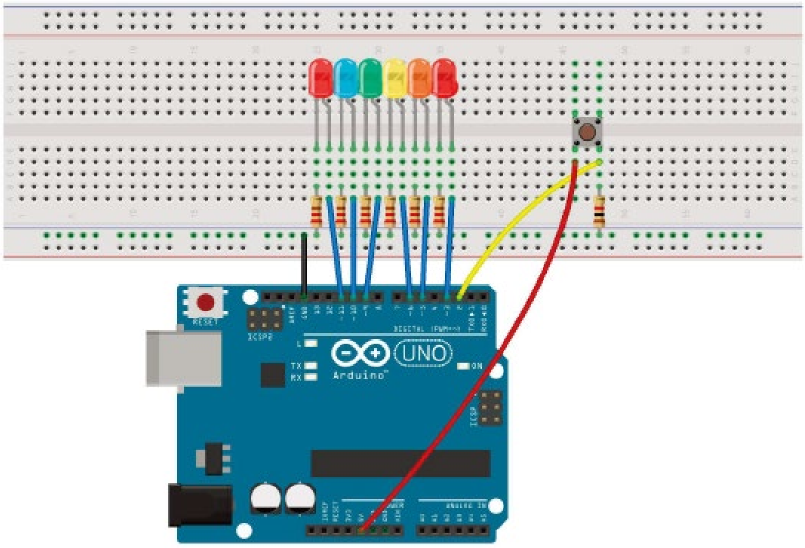


Figure 11.17 Structure of Making LED Dice[1]

Place 6 LEDs as shown in the figure. The cathode of each LED is connected to GND through a resistor. Connect the anodes of 6 LEDs to pins 3, 5, 6, 9, 10, and 11 of the Arduino board, as shown in the figure.

11.7 Communicate Serial with PC

1) 1) Communicate through a Serial monitor.

Output to Serial monitor.

```
void setup()
{
  Serial.begin(9600);
}

void loop()
{
  Serial.println("Hello Arduino");
  delay(1000);
}
```

[1] Project Repository at *t.ly/r-cT*

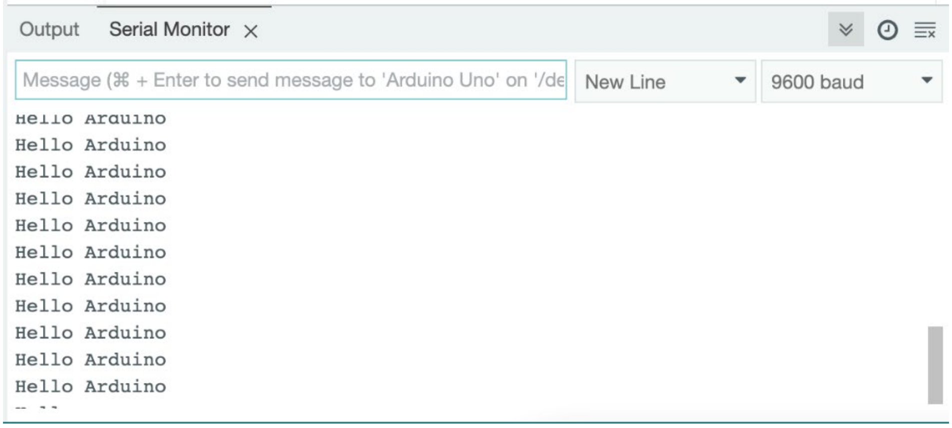


Figure 11.18 Output of Serial Monitor

- Serial.begin(baud) sets the data rate per second when transmitting data. Usually, wireless communication is set as a default of 9600bps for XBee or Bluetooth. If the board speed is increased, data can be sent faster, but data may be lost during communication.
- Serial.println(val, format) or Serial.println(val) may output data in a new line.

11.8 Making a Streetlight

1) What is Cds?

Cds is called cadmium sulfide or Photoresist. Cds is a sensor whose resistance value varies depending on the amount of light. It is used to judge the degree of lightness and darkness according to the standard without measuring the LUX value. It has the advantage that the price is relatively low and the disadvantage that the precision is greatly reduced.

Figure 11.19 Cadmium Sulfide or Photoresist

These days, cadmium-based heavy metals are included and are related to environmental pollution, so Phototransistors that are more expensive but can measure precise values are used.

2) Making a Streetlight Using Cds

Part Name	Quantity	Part Name	Quantity
Resistor 220Ω	1ea	Resistor 10kΩ	1ea
LED	1ea	Cds sensor	1ea

Construct the circuit as follows.

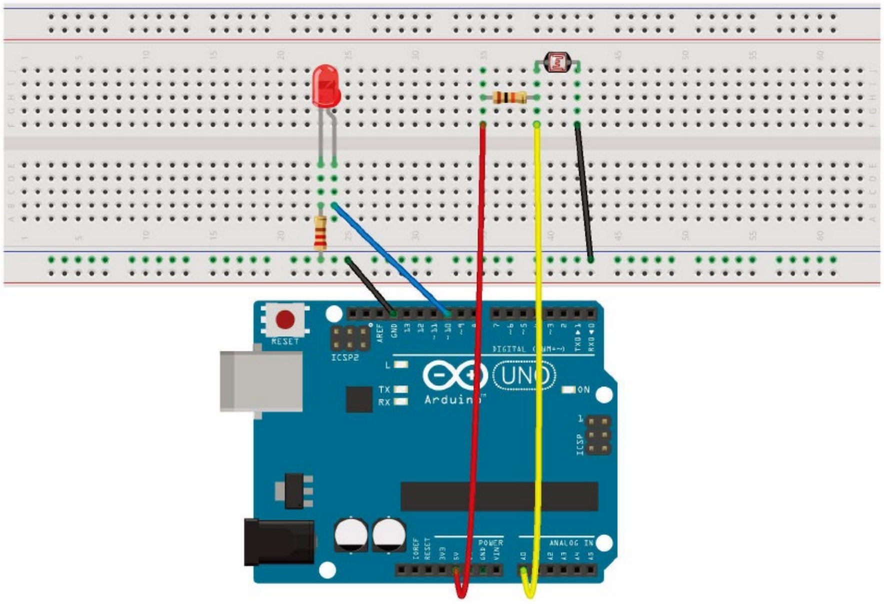


Figure 11.20 Structure of Streetlight Using Cds

Open the sketch, input the code as follows and upload it.

```

const int ledPin = 10;
const int analogPin = A0;

void setup() {

}

void loop() {
  int sensorInput = analogRead(analogPin);
  analogWrite(ledPin, sensorInput/4);
}
```

Expose the light sensor to light or hide it from the light, and check the value change.

11.9 Using a Potentiometer

11.9.1 Analog Signal Input/Output

The Arduino board has analog input pins, but analog output pins cannot be found on the board. This is because the Arduino board operates on a digital basis. However, there are times when you need to use an analog output when using an Arduino. In this case, PWM is used. PWM (Pulse Width Modulation) can be used on the pins with '~' next to the digital pin number. The Arduino Uno board can output PWM on pins 3, 5, 6, 9, 10, and 11.

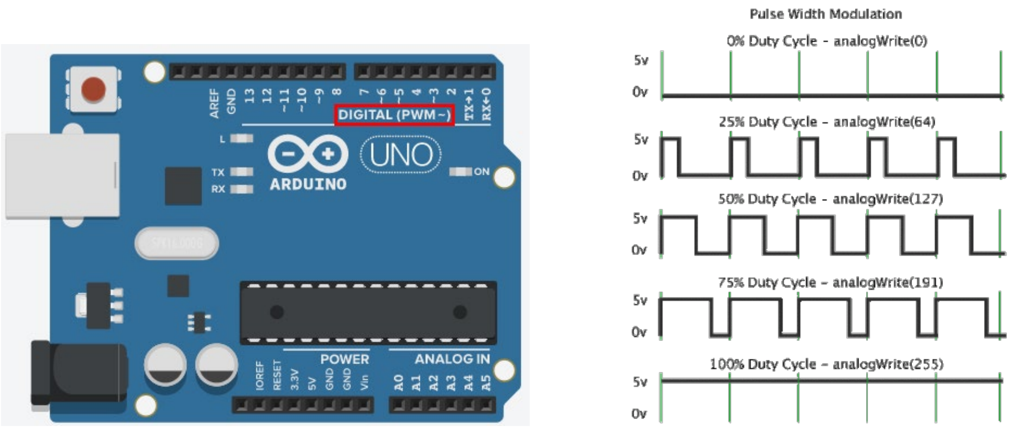


Figure 11.21 Digital PWM (Pulse Width Modulation)

A potentiometer is a resistor in which the user can arbitrarily change the resistance value. ~~And~~ The potentiometer has three pins. Suppose the resistance value changes after connecting power to both pins, a signal modified according to the resistance value is output. When the potentiometer value is turned to the + pole, the maximum value comes out, and when it is turned to the - pole, it approaches 0. Potentiometers have three legs, but polarity doesn't matter. It works if only Vout is connected to an analog pin.

11.9.2 Circuit Configuration and Programming

Construct a potentiometer circuit as follows:

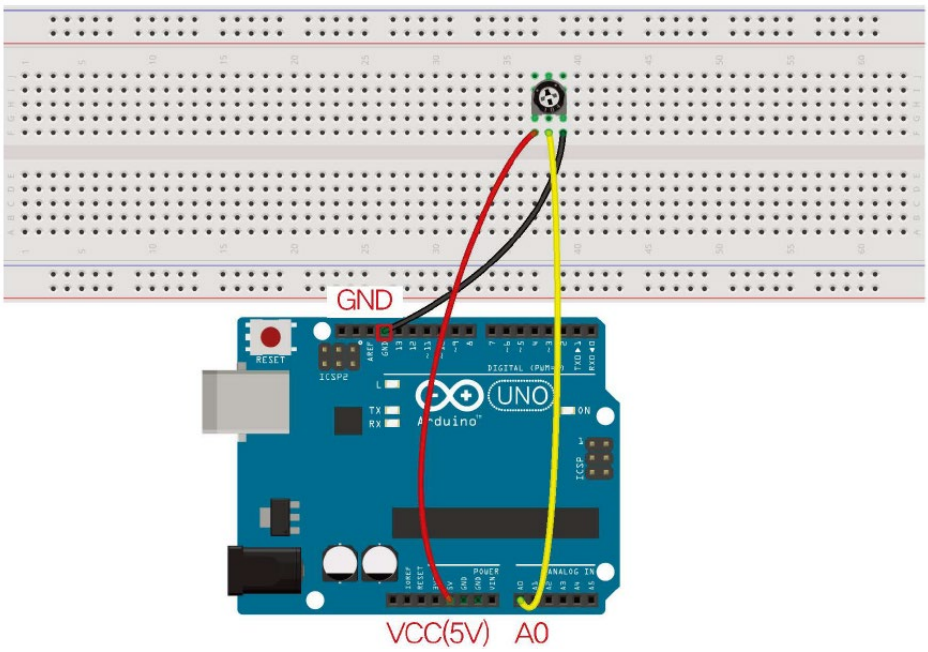


Figure 11.22 Structure of Using a Potentiometer

Connect the pins at both ends of the potentiometer to 5V and GND, respectively. Connect the center pin of the potentiometer to the A0 pin of the Arduino board.

```
const int analogPin = A0;

void setup() {
  Serial.begin(115200);
}

void loop() {
  int analogValue = analogRead(analogPin);
  Serial.println(analogValue);
}
```

When the serial monitor window appears, set the communication speed to 115200 in the lower right corner.

If you use a potentiometer, you can see that a value between 0 and 1023 comes out.

11.10 Adjust LED Brightness According to Potentiometer Input Values

To adjust the brightness of the LED according to the potentiometer value, configure the circuit as follows:

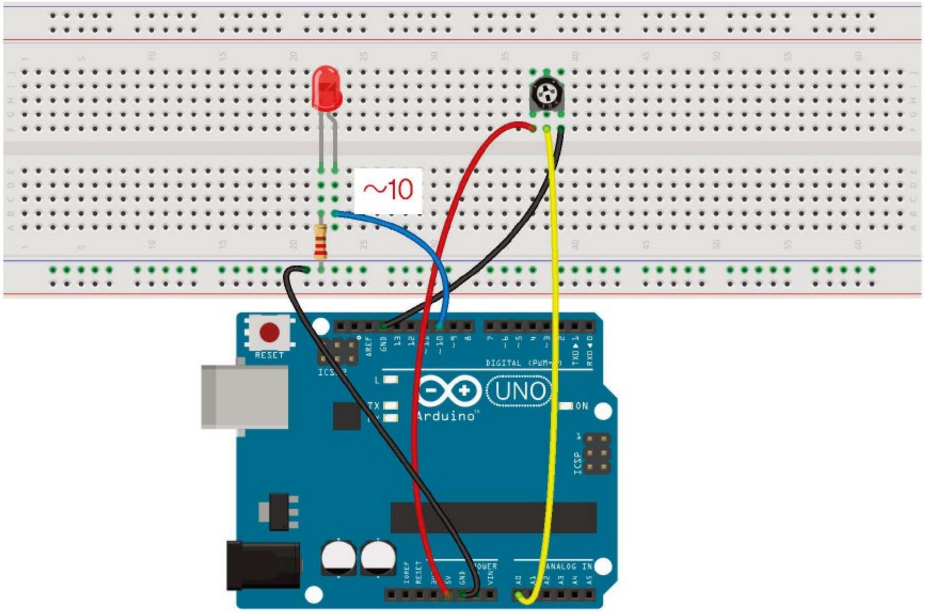


Figure 11.23 Structure to adjust LED Brightness Based on a Potentiometer

Add the LED circuit to the previously constructed circuit and modify the example.

```
const int ledPin = 10;
const int analogPin = A0;

void setup() {

}

void loop() {
  int sensorInput = analogRead(analogPin);
  analogWrite(ledPin, sensorInput/4);
}
```

The analogRead function reads the analog value of the pin passed as an argument as a value between 0 and 1023. The sensorInput value read by the analogRead function is divided by four and sent to ledPin. A value between 0 and 1023 can be divided by 4 to export a value between 0 and 255. Turning the potentiometer value to one end turns the LED off, and turning it to the other achieves maximum brightness.

11.11 Digital LED Bar Meter

After composing 6 LEDs in a row, turn on the LED as much as the potentiometer is turned on. The input value of the potentiometer is a value between 0 and 1023, and this section is divided by 7. There are six boundary points: 146, 292, 438, 584, 730, and 876. The LED is turned on one by one every time each boundary point is passed.

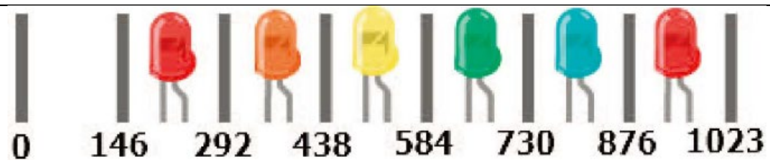


Figure 11.24 LEDs that light up one by one depending on the size of the potentiometer

Construct the circuit as follows:

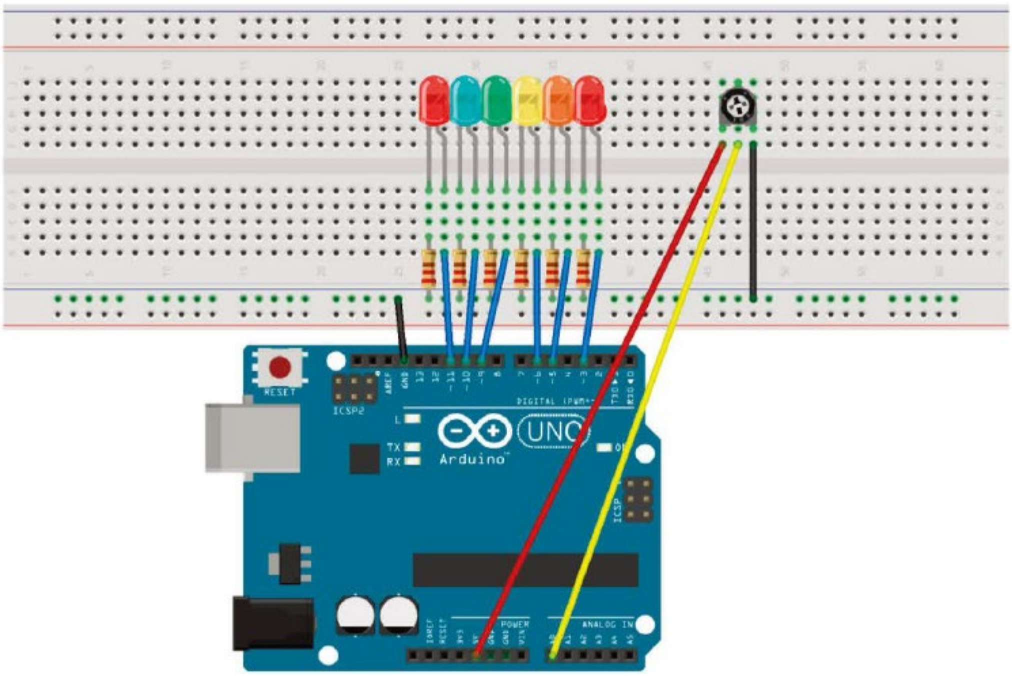


Figure 11.25 Structure of Digital LED Bar Meter

Configure to 6 LEDs as shown in the circuit. The cathode of each LED is connected to GND through a resistor. Connect the anodes of the 6 LEDs to pins 3, 5, 6, 9, 10, and 11 of the Arduino board sequentially from the left with wires. Connect the pins at both ends of the potentiometer to 5V and GND, respectively. Connect the center pin of the potentiometer to pin A0 of the Arduino board.

```
const int led[6] = { 3, 5, 6, 9, 10, 11 };
const int analogPin = A0;

```

```
void setup() {
  for(int x=0;x<=5;x++) {
    pinMode(led[x], OUTPUT);
  }
}

void loop() {
  int sensorInput = analogRead(analogPin);

  if(sensorInput > 1024/7*(1+0)) // 146
    digitalWrite(led[0], HIGH);
  else digitalWrite(led[0], LOW);

  if(sensorInput > 1024/7*(1+1)) // 292
    digitalWrite(led[1], HIGH);
  else digitalWrite(led[1], LOW);

  if(sensorInput > 1024/7*(1+2)) // 438
    digitalWrite(led[2], HIGH);
  else digitalWrite(led[2], LOW);

  if(sensorInput > 1024/7*(1+3)) // 584
    digitalWrite(led[3], HIGH);
  else digitalWrite(led[3], LOW);

  if(sensorInput > 1024/7*(1+4)) // 730
    digitalWrite(led[4], HIGH);
  else digitalWrite(led[4], LOW);

  if(sensorInput > 1024/7*(1+5)) // 876
    digitalWrite(led[5], HIGH);
  else digitalWrite(led[5], LOW);
}
```

Set the pinMode() function to the OUTPUT of each item of the array, which is the led[0]~led[5] pins. Call the analogRead() function to read the analogPin value as sensorInput variable. If the sensorInput value is greater than 146, which is 1024/7, the first LED is turned on by calling the digitalWrite() function and giving a HIGH value to the led[0] pin. If the sensorInput value is less than or equal to 146, a LOW value is given to the led[0] pin to turn the first LED off. In the same way for the rest of the LEDs, if the threshold value of the corresponding LED exceeds, the LED is turned on. Otherwise, the LED is turned off.

This code can be generalized using the for a statement as follows:

```
const int led[6] = { 3, 5, 6, 9, 10, 11 };
const int analogPin = A0;

void setup() {
  for(int x=0;x<=5;x++) {
```

```
    pinMode(led[x], OUTPUT);
    }
  }

void loop() {
  int sensorInput = analogRead(analogPin);

  for(int n=0;n<=5;n++) {
   if(sensorInput > 1024/7*(1+n))
      digitalWrite(led[n], HIGH);
   else digitalWrite(led[n], LOW);

  }
}
```


11.12 Play Music with Arduino

11.12.1 Make a Sound Using a Buzzer

The Piezo buzzer is a device that uses crystal properties (piezoelectric material) such as crystal or ceramic, and a thin plate is placed on the piezoelectric material to make a sound due to the piezoelectric effect.

- Piezoelectric material: A material using the principle that an electric potential difference (voltage) occurs when pressure is applied to a certain crystal, and conversely, when the electric potential difference (voltage) occurs in this material, physical displacement is generated.
- Piezoelectric effect: When pressure is applied, a voltage is generated, or when a voltage is given, pressure (expansion, condensation) is generated.

In other words, the principle of sound generation in the Piezo buzzer is as follows: When a thin plate is placed on the piezoelectric material, and a voltage is applied to the piezoelectric material, the piezoelectric material vibrates and collides with the plate to make a sound. Piezo buzzers can be purchased at a price of less than 1,000 won.

The buzzer has different sounds depending on the frequency. For example, if a sound of 440 Hz is made, 440 Hz means vibration 440 times per second. The time it takes to vibrate once is as follows: 1/440 = 0.00227272...[s]. It is about 2.2727ms (milliseconds) and 2272.7272us (microseconds). Since 0 and 1 are repeated for 2273us seconds by rounding, one is repeated for 2273/2us, and 0 is repeated for 2273/2us.

11.12.2 How to Use a Buzzer

The Piezo buzzer consists of two electrode terminals and has polarity. The upper surface of the Piezo buzzer is written as (+), or the (+) electrode can be connected to the side with a small groove next to it. However, there is also a Piezo buzzer that does not have to worry about the (+) and (-) electrodes of the component. The Piezo buzzer we will use can be connected to the Arduino board regardless of polarity. The table below shows octaves and the scale's standard frequencies. By giving a frequency signal to the Piezo buzzer, it makes the desired sound of the scale.

(unit : Hz)

octave / scale	1	2	3	4	5	6	7	8
C(Do)	32.7032	65.4064	130.8128	261.6256	523.2511	1046.502	2093.005	4186.009
C#	34.6478	69.2957	138.5913	277.1826	554.3653	1108.731	2217.461	4434.922
D(Re)	36.7081	73.4162	146.8324	293.6648	587.3295	1174.659	2349.318	4698.636
D#	38.8909	77.7817	155.5635	311.1270	622.2540	1244.508	2489.016	4978.032
E(Mi)	41.2034	82.4069	164.8138	329.6276	659.2551	1318.510	2637.020	5274.041
F(Fa)	43.6535	87.3071	174.6141	349.2282	698.4565	1396.913	2793.826	5587.652
F#	46.2493	92.4986	184.9972	369.9944	739.9888	1479.978	2959.955	5919.911
G(Sol)	48.9994	97.9989	195.9977	391.9954	783.9909	1567.982	3135.963	6271.927
G#	51.9130	103.8262	207.6523	415.3047	830.6094	1661.219	3322.438	6644.875
A(La)	55.0000	110.0000	220.0000	440.0000	880.0000	1760.000	3520.000	7040.000
A#	58.2705	116.5409	233.0819	466.1638	932.3275	1864.655	3729.310	7458.620
B(Ci)	61.7354	123.4708	246.9417	493.8833	987.7666	1975.533	3951.066	7902.133

Figure 11.26 Table Showing Octaves and Scale's Standard Frequencies

The scale we are familiar with is 4 octaves. The sound "Do" is a sound with a frequency of 261.6256 Hz, which is "C" in a 4-octave scale.

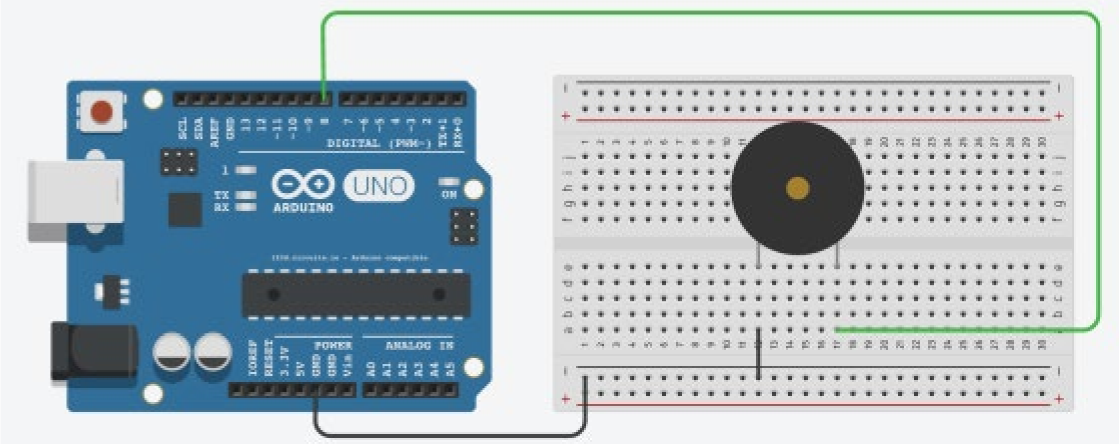


Figure 11.27 Structure of Using Buzzer

```
int speakerSensor=8; // store 8, in the speakerSensor variable
void setup() {
  pinMode(speakerSensor, OUTPUT); // It is output through pin 8
}

void loop() {
  digitalWrite(speakerSensor, HIGH);
  delay(1000); // wait 1 second
  digitalWrite(speakerSensor, LOW);
  delay(1000);
}
```

2) Expressing the Scale

The buzzer does not just make a "tick" sound only. Using the tone() function, you can express a scale such as "CDEFGAB". Let's express the "CDEFGAB" scale as a function of tone().

1) Tone() Function:

```
tone(pin number, pitch,duration)
- pin number: Set the pin number connected to the buzzer.
- pitch: pitch settings.
- duration: Setting the time to make a sound.
```

2) Expressing the sound scales as software:

```
int note_c4=262;
int note_d4=294;
int note_e4=330;
int note_f4=349;
int note_g4=392;
int note_a4=440;
```

```
int note_b4=494;
int note_c5=523;

int speakerSensor=8;
int noteDuration=500;

void setup() {
  pinMode(speakerSensor,OUTPUT);
}

void loop() {
  tone(speakerSensor,note_c4, noteDuration);
  delay(500);
  tone(speakerSensor,note_d4, noteDuration);
  delay(500);
  tone(speakerSensor,note_e4, noteDuration);
  delay(500);
  tone(speakerSensor,note_f4, noteDuration);
  delay(500);
  tone(speakerSensor,note_g4, noteDuration);
  delay(500);
  tone(speakerSensor,note_a4, noteDuration);
  delay(500);
  tone(speakerSensor,note_b4, noteDuration);
  delay(500);
  tone(speakerSensor,note_c5, noteDuration);
  delay(500);
}
```

3) Expressing airplane songs to software:

```
int piezo = 3;
int numTones = 25;
int tones[] = {330, 294, 261, 294, 330, 330, 330, 294, 294, 294,
  330, 392, 392, 330, 294, 261, 294, 330, 330, 330,
  294, 294, 330, 294, 261};

void setup() {
  pinMode(piezo, OUTPUT);
}

void loop() {
  for (int i = 0; i < numTones; i++) {
    tone(piezo, tones[i]);
    delay(500);
  }
  noTone(piezo);
  delay(5000);
}
```

11.13 Making a Digital Piano

Parts required: Arduino board, Breadboard, Piezo buzzer, Button 3ea, Resistor(1KΩ) 3ea, Jumper Wire

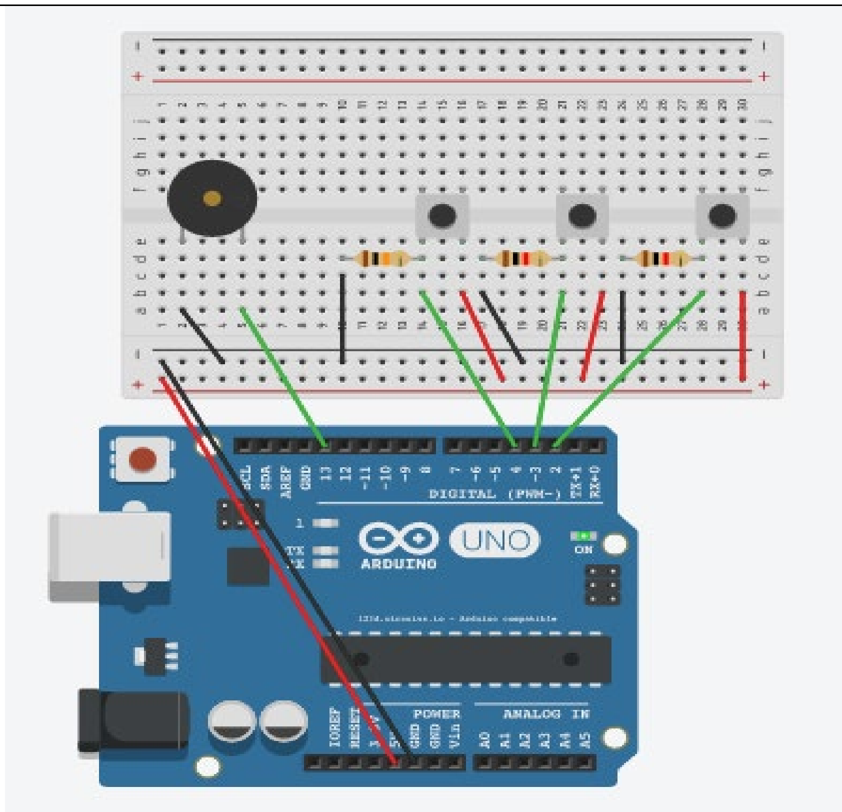


Figure 11.28 Structure of Using Buttons and Buzzer

```
int Pin[]={2,3,4};
int Note[]={262,294,330};

void setup() {
  for(int i=0;i<3;i++){
    pinMode(Pin[i], INPUT);
  }
}

void loop() {
  for(int i=0;i<3;i++){
    if(digitalRead(Pin[i])==HIGH){
      tone(13, Note[i],20);
    }
  }
}
```

11.14 Making a Button Piano

Connect the Manual buzzer and push the button to the Arduino board.

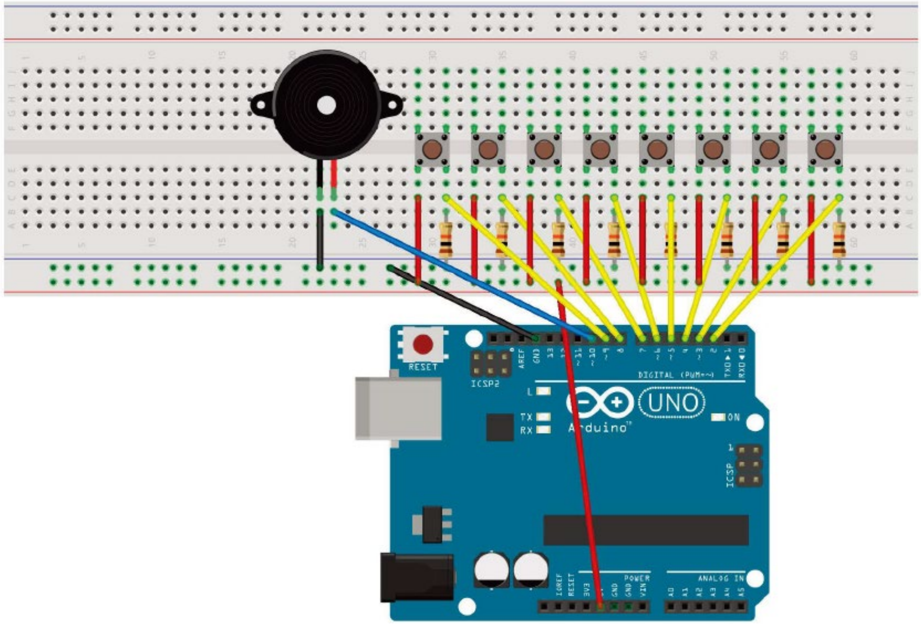


Figure 11.29 Structure of Button Piano Using Buzzer

Connect the + pin of the buzzer to pin 10 of the Arduino board. The other pin of the buzzer is connected to the GND pin. Place eight buttons as shown in the picture and connect one pin of each button with 5V. (red wire part). Connect the other pin of each button to GND through a 10KΩ resistor (black wire part). Connect the other pin of each resistor to pins 2~9 of Arduino in order. At this time, be careful that the legs of the resistor do not touch each other.

After completing the circuit configuration, write the code as follows:

```
const int BUZZER = 10;
const int button[8] = { 9, 8, 7, 6, 5, 4, 3, 2 };

const int note[8] = {
  262, 294, 330, 349, 393, 440, 494, 523,
};

void setup() {
  for(int n=0;n<=7;n++) {
  pinMode(button[n], INPUT);
  }
}

void loop() {
  if(digitalRead(button[0]) == HIGH) {
  tone(BUZZER, note[0]);
  } else if(digitalRead(button[1]) == HIGH) {
  tone(BUZZER, note[1]);
  } else if(digitalRead(button[2]) == HIGH) {
  tone(BUZZER, note[2]);
  } else if(digitalRead(button[3]) == HIGH) {
  tone(BUZZER, note[3]);
```

```
} else if(digitalRead(button[4]) == HIGH) {
tone(BUZZER, note[4]);
} else if(digitalRead(button[5]) == HIGH) {
tone(BUZZER, note[5]);
} else if(digitalRead(button[6]) == HIGH) {
tone(BUZZER, note[6]);
} else if(digitalRead(button[7]) == HIGH) {
tone(BUZZER, note[7]);
} else {
noTone(BUZZER);
}
}
```

Declare the BUZZER constant and enter pin 10. Declare the constant button array and enter pins from 9 to 2. Declare a constant note array and enter a frequency corresponding to each sound. If the value of the button[0] pin is HIGH by calling the digitalRead() function, the tone() function is called to output a sound corresponding to note[0] to the BUZZER pin. Process the rest of button[1]~button[7] similarly. If no button is pressed, the buzzer stops by calling the noTone() function.

11.15 Measuring Distance Using an Ultrasonic Sensor

Ultrasound refers to a sound with a high frequency (about 20 kHz or higher) that is inaudible to the human ear, and the ultrasonic sensor uses it. The ultrasonic sensor is a sensor that measures distance using ultrasonic waves. In addition, ultrasonic sensors can measure speed, concentration and viscosity, and water level or snow cover.

① HC-SR04 Features

- Analog signal
- High performance, low price
- Sensor using ultrasonic

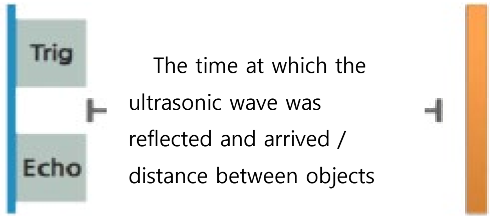
② Specifications

- Operating voltage 5V
- Operating current 15mA
- Operating frequency 40Hz
- Generation frequency 40kHz
- Measuring distance 2~400cm
- Size 45x 20 x 15mm

③ Pinout

④ Operating principle of ultrasonic sensor

Vcc / Trig / Echo / Gnd



The distance to the object in front can be calculated using the time it takes for the ultrasonic wave to return to the echo from the 40 kHz ultrasonic wave from the Trig. The speed of sound is 340 m/s, and it takes 29 microseconds (μs*) to travel 1 cm.

Distance (cm) = Time / 29 / 2

Parts required: Arduino board, Breadboard, Piezo Buzzer, Melody IC, one resistor (1KΩ), Wire

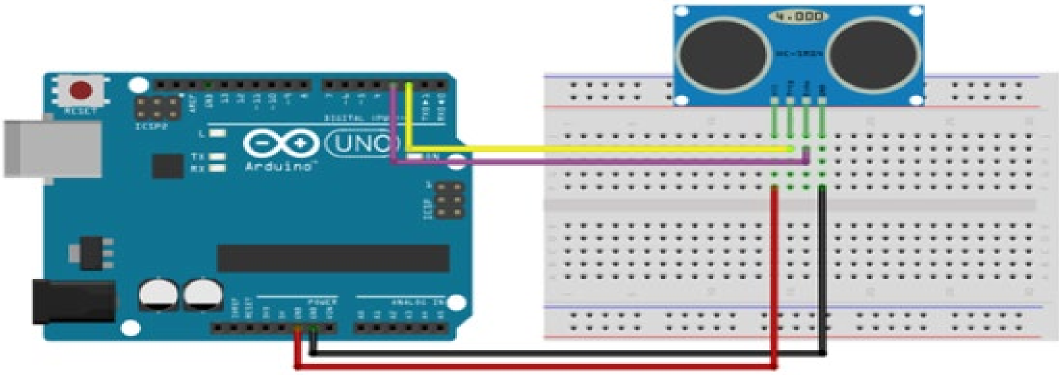


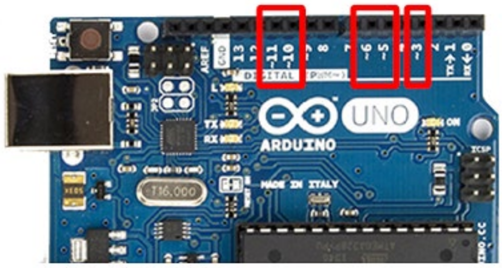
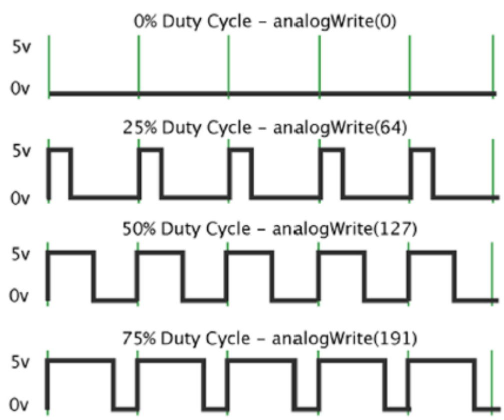
Figure 11.30 Structure of Using an Ultrasonic Sensor

```
int trigPin=2;
int echoPin=3;

void setup() {
  pinMode(echoPin, INPUT);
  pinMode(trigPin, OUTPUT);
  Serial.begin(9600);
}

void loop(){
  long duration;
  float dis;
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  duration = pulseIn(echoPin, HIGH);
  dis=duration/29/2;
  Serial.print(dis);
  Serial.print("cm");
  Serial.println();
  delay(100);
}
```

- Using the ultrasonic sensor and 3 LEDs (Red, Yellow, and Green), let's turn the LED on according to the distance. The green LED turns on when the distance is greater than 5cm. When the distance is less than 5cm, the yellow LED turns on, and when the distance is less than 2cm, the red LED turns on.
- Let's make a harp that plays notes according to the distance using the ultrasonic sensor

11.16 Control the Angle of the Servomotor

A motor is an electronic component that converts electrical energy into rotational or linear motion. Motors are also used in many fields, such as automobiles, fans, and robots in real life. The servo motor (SG90) we will use is a servo motor that can rotate 0 to 180 degrees instead of 360 degrees. The rotation angle or speed can be controlled by controlling the rotation position. To use the SG90, you need to handle the PWM signal, and let's control the SG90 through Arduino.

	■ Rotation angle 0~180 degrees ■ control to angle and speed ■ Operating voltage 4.8~7.2V ■ Current voltage 0.2~0.7A ■ Three connecting wires - VCC is red, GND is brown, and the signal line is orange ■ Torque 1.8kg.cm ■ Size 22.2 x 11.8 x 31 mm
 - Uno board: Total of 6 PWM output pins (~3, ~5, ~6, ~9, ~10, ~11) - A wave (~) is displayed on the digital pin side. - PWM output: Abbreviation for Pulse Width Modulation, which means to control the width of vibration. • An output method that creates an analog signal by adjusting the duty of HIGH for each cycle	 Arduino can divide 0-5V into 0-255 (256 types) signals by outputting a PWM signal through the PWM pin

Parts required: Arduino Board, Servo Motor, Wire

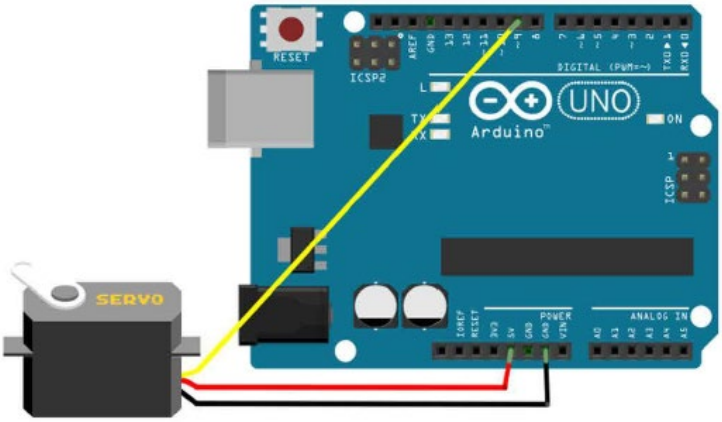


Figure 11.31 Structure of Using Servo Motor

※ setting to the Servo Motor center

```
#include <Servo.h> //Include the Servo.h library.
Servo myservo;  //Declare servo motor (myservo)

void setup(){
  myservo.attach(9);  // Connect the servo motor signal line to digital number 9
(PWM)  myservo.write(90); //Move the servo motor to the 90-degree position.
}

void loop(){
  delay(100); //0.1 second delay
}
```

※ Precautions when using ‘Servo.h’ library

- It can control up to 12 servo motors
- When using Uno board, the PWM of digital pins 9 and 10 cannot be used even if a servo motor is not connected to the corresponding pin.
- The maximum current that can be supplied from one pin on the Uno board is 40mA. The maximum current supplied from all pins cannot exceed 200mA, so it is necessary to check when driving the motor. If necessary, an external power source should be used. In this case, the GND of the Arduino and the GND of the external power should be connected.

※ Changing the servo motor angle

```
#include <Servo.h> //Include the Servo.h library.
Servo myservo; //Declare servo motor (myservo)
int pos=0; //Declare variable pos (display the servo position)

void setup(){
```

```
  myservo.attach(9); // Connect the servo motor signal line to digital number 9 (PWM)
}
void loop(){
  for(pos=0; pos<=180;pos+=1){ //Start pos from 0 and add 1 to 180.
    myservo.write(pos); //Move the servo motor to the pos position.
    delay(15); //0.015 second delay
  }
  for(pos=180; pos>=0;pos-=1){ // Subtract pos by 1 from 180 to 0.
    myservo.write(pos); //Move the servo motor to the pos position.
    delay(15); //0.015 second delay
  }
}
```

※ Changing the servo motor angle using a potentiometer

Parts required: Arduino Board, Servo Motor, Potentiometer 10K, Jumper Wire

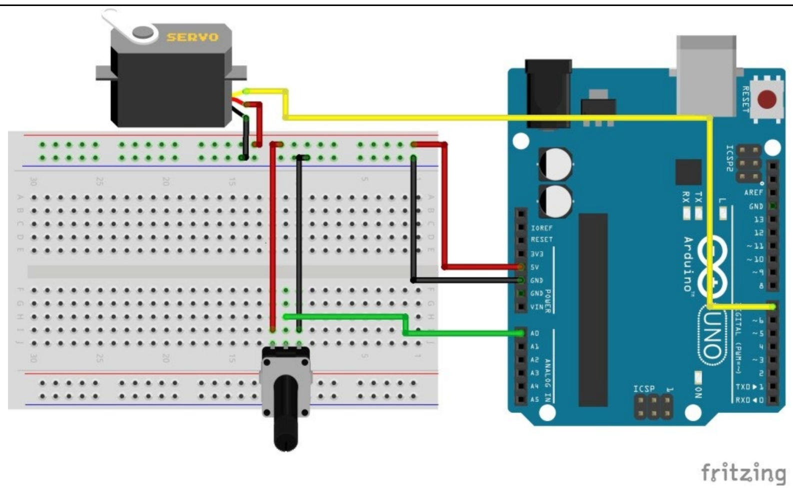


Figure 11.32 Structure of Changing the Servo Motor Angle Using a Potentiometer

```
#include <Servo.h> //Include the Servo.h library.
Servo myservo; //Declare servo motor (myservo)

void setup(){
  myservo.attach(7); // Connect the servo motor signal line to digital number 7 (PWM)
}

void loop(){
  int pos = analogRead(A0); //Read the potentiometer value from A0 pin.
  pos = map(value, 0, 1023, 0, 179); // Converts the value input to pin A0 into an angle.
  myservo.write(pos); //Move the servo motor to the pos position.
  delay(20);
}
```

11.17 Using a Joystick

A Joystick is a device capable of detecting movement in all directions, including front, rear, left, right, and diagonal directions, using a handle. The Joystick consists of two potentiometers and one push button. The two potentiometers indicate in which direction the potentiometers were pressed. The switch sends a LOW value when the Joystick handle is pressed.

The Joystick is connected to the Arduino by five pins. The three pins are input pins to Arduino, and VCC and GND connect the other two pins.

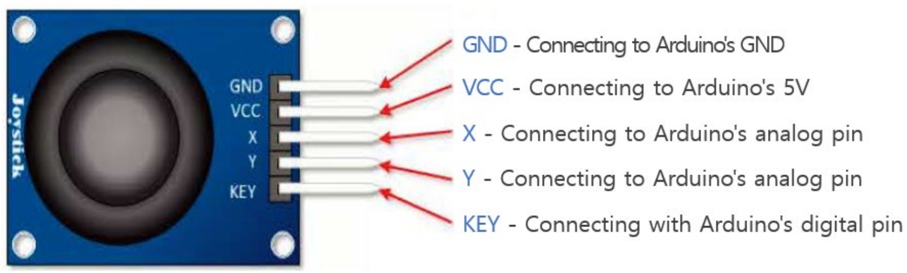


Figure 11.33 Structure of Joystick

To control the Joystick handle, you need to understand which direction is X and which direction is Y. In addition, it is necessary to know whether the Joystick handles move in the X or Y direction. Arduino measures the position of the Joystick handle using analog input. Analog input provides a range value between 0 and 1023.

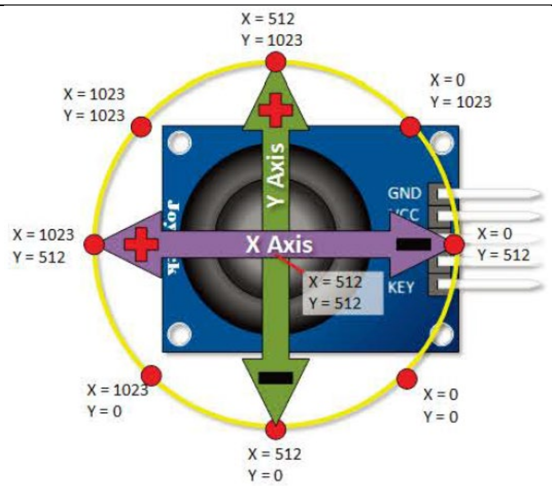


Figure 11.34 Direction of Joystick Output

To receive Joystick input, write an example as follows:

```
const int Xin= A0; //Joystick X coordinate input pin
const int Yin = A1; // Joystick Y coordinate input pin
const int KEYin = 3; // Joystick push button input pin

void setup () {
  pinMode (KEYin, INPUT);
  Serial.begin (115200);
}

void loop () {
  int xVal = analogRead (Xin);
  int yVal = analogRead (Yin);
  int buttonVal = digitalRead (KEYin);

  Serial.print("X = ");
  Serial.println (xVal, DEC);

  Serial.print ("Y = ");
  Serial.println (yVal, DEC);

  Serial.print("Button is ");
  if (buttonVal == HIGH) {
  Serial.println ("not pressed");
  } else {
  Serial.println ("PRESSED");
  }
}
```

The Xin constant is Arduino’s A0 pin and receives the X coordinates of the Joystick. The Yin constant is Arduino’s A1 pin and receives the Y coordinates of the Joystick. The KEYin constant is three pins and receives a button from the Joystick. The analogRead function is called to input the Xin pin value to the xVal variable and the Yin pin value to the yVal variable. The value received from the analogRead function is between 0 and 1023. Call the digitalRead function and enter the KEYin pin value into the buttonVal variable. When the button is pressed (High), the phrase “Button is PRESSED” is output, and when the button is not pressed (LOW), the message “Button is not pressed” is output.

It is checked that the X and Y values change by moving up, down, left, and right using a Joystick. Check that the button is pressed when pressing the Joystick.

11.18 Numbers and Word Display with 7 Segment

7-segment is a device that can display decimal digits from 0 to 9 by arranging LEDs, as shown in the figure, and selecting some of them to emit light. There are seven 7-segment types: a common cathode type and an anode type. GND is connected to the cathode type, and Vcc is connected to the composition for the anode type. Here, let’s practice with the anode type.

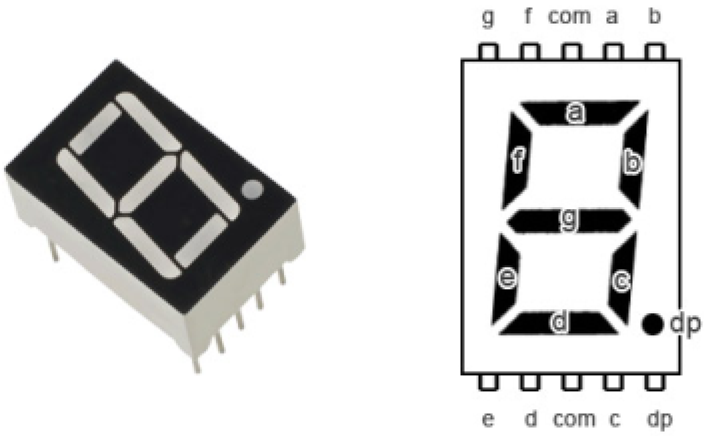


Figure 11.35 Structure of 7 Segments

Parts required: Arduino Board, Breadboard, 7 Segments, 1 Resistor (330Ω), Wire

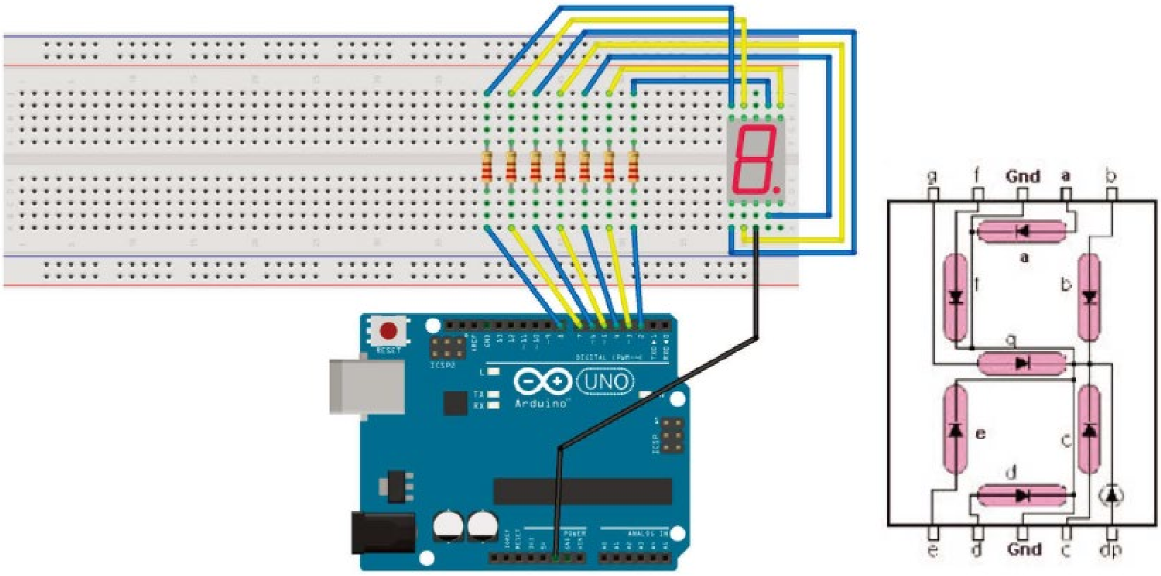


Figure 11.36 Structure of Using 7 Segment

First, initialize all of the 7-segment a~g LEDs and turn them on:

```
const unsigned int led_a = 2;
const unsigned int led_b = 3;
const unsigned int led_c = 4;
const unsigned int led_d = 5;
const unsigned int led_e = 6;
```

```
const unsigned int led_f = 7;
const unsigned int led_g = 8;

void setup() {
 // Initialize the led
  pinMode(led_a, OUTPUT);
  pinMode(led_b, OUTPUT);
  pinMode(led_c, OUTPUT);
  pinMode(led_d, OUTPUT);
  pinMode(led_e, OUTPUT);
  pinMode(led_f, OUTPUT);
  pinMode(led_g, OUTPUT);

  // turn on the led
  digitalWrite(led_a, HIGH);
  digitalWrite(led_b, HIGH);
  digitalWrite(led_c, HIGH);
  digitalWrite(led_d, HIGH);
  digitalWrite(led_e, HIGH);
  digitalWrite(led_f, HIGH);
  digitalWrite(led_g, HIGH);
}

void loop() {

}
```

This time, the above example is generalized using a for statement and a primary array. Modify the example as follows:

```
const unsigned int led[7] = { 2, 3, 4, 5, 6, 7, 8 };

void setup() {
  // Initialize the led
  for(int x=0;x<7;x++) {
  pinMode(led[x], OUTPUT);
  }

    // turn on the led
  for(int x=0;x<7;x++) {
  digitalWrite(led[x], HIGH);
  }
}

void loop() {

}
```

This time, it repeats turning on and off the LEDs from a~ g in sequence:

```
const unsigned int led[7] = { 2, 3, 4, 5, 6, 7, 8 };

void setup() {
  for(int x=0;x<7;x++) {
  pinMode(led[x], OUTPUT);
  }
}

void loop() {
  for(int x=0;x<7;x++) {

 // turn off all LEDs
  for(int x=0;x<7;x++) {
    digitalWrite(led[x], LOW);
  }

  digitalWrite(led[x], HIGH);

    delay(1);//1/3.5=0.286Hz
  }
}
```

Since it takes 0.5 seconds to turn each LED on and off, it takes about 3.5 seconds in total.

To display a number, you can check if 0 is displayed by writing an example like this:

```
const unsigned int led[7] = { 2, 3, 4, 5, 6, 7, 8 };

const unsigned int num_0[7] = { 1, 1, 1, 1, 1, 1, 0 };/*0*/

void display_init() {
  for(int x=0;x<7;x++) {
  pinMode(led[x], OUTPUT);
  }
}

void display_clear() {
  for(int x=0;x<7;x++) {
  digitalWrite(led[x], LOW);
  }
}

void setup() {
  display_init();

  display_clear();

  for(int x=0;x<7;x++) {
  digitalWrite(led[x], num_0[x]==1?HIGH:LOW);
  }
```

```
}

void loop() {

}
```

Using a secondary array, you can display any number from 0 to 9:

```
const unsigned int led[7] = { 2, 3, 4, 5, 6, 7, 8 };

const unsigned int num[10][7] = {
  { 1, 1, 1, 1, 1, 1, 0, },/*0*/
  { 0, 1, 1, 0, 0, 0, 0, },/*1*/
  { 1, 1, 0, 1, 1, 0, 1, },/*2*/
  { 1, 1, 1, 1, 0, 0, 1, },/*3*/
  { 0, 1, 1, 0, 0, 1, 1, },/*4*/
  { 1, 0, 1, 1, 0, 1, 1, },/*5*/
  { 1, 0, 1, 1, 1, 1, 1, },/*6*/
  { 1, 1, 1, 0, 0, 1, 0, },/*7*/
  { 1, 1, 1, 1, 1, 1, 1, },/*8*/
  { 1, 1, 1, 1, 0, 1, 1, },/*9*/
};

void display_init() {
  for(int x=0;x<7;x++) {
  pinMode(led[x], OUTPUT);
  }
}

void display_clear() {
  for(int x=0;x<7;x++) {
  digitalWrite(led[x], LOW);
  }
}

void display_number(int n) {
  if(0<=n&&n<=9) {
  for(int x=0;x<7;x++) {
    digitalWrite(led[x], num[n][x]==1?HIGH:LOW);
  }
  }
}

void setup() {
  display_init();
}

void loop() {
```

```
for(int n=0;n<=9;n++) {
display_clear();
display_number(n);
delay(500);
}
}
```

11.19 Making a Decimal Counter with Four Digit 7 segments

This time, let’s display a number in 4 digits, 7 segments of 4 digits. The 4-digit 7-segment consists of the following 4 with 7-segments.

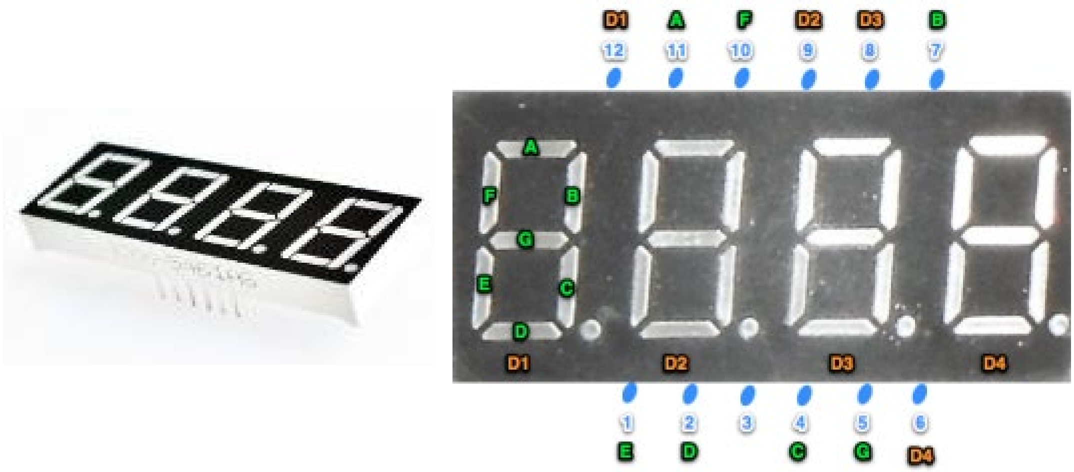


Figure 11.37 Structure of 4 Digit 7 Segments

Each 7 segment consists of a figure 8 LED. In practice, 8 LEDs are used per segment, so 56 LEDs can be turned on and off. The 8th LED is a dot to the right of the number, which can indicate a decimal point. Each LED has a name from A to G. The LED representing the decimal point is DP (decimal point). The pins that separate each segment are COM1, COM2, COM3, and COM4. These pins must be controlled with high frequency to display different numbers.

The 4-digit and 7-segment circuits have a common cathode and a common anode circuit, so they must be used separately. If the LED corresponding to ~~an of~~ the leftmost 7-segment is turned on by composing the circuit, it is a common cathode.

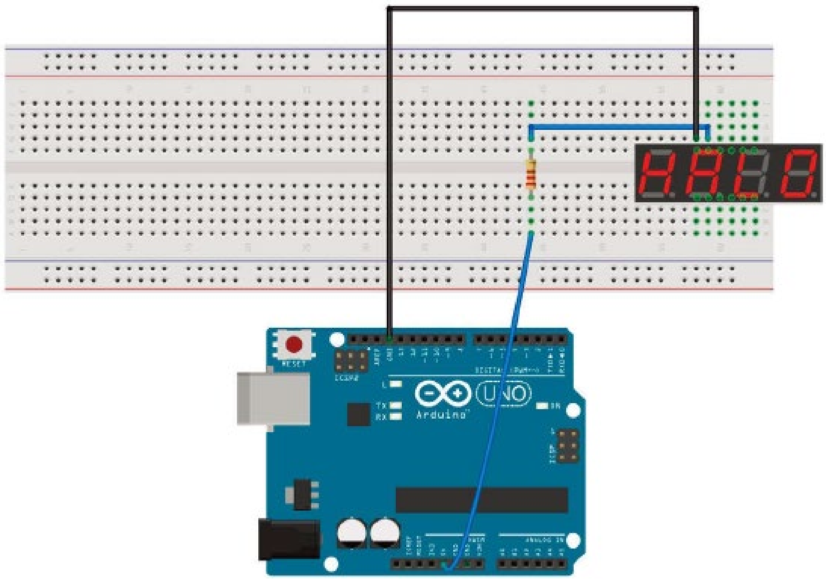
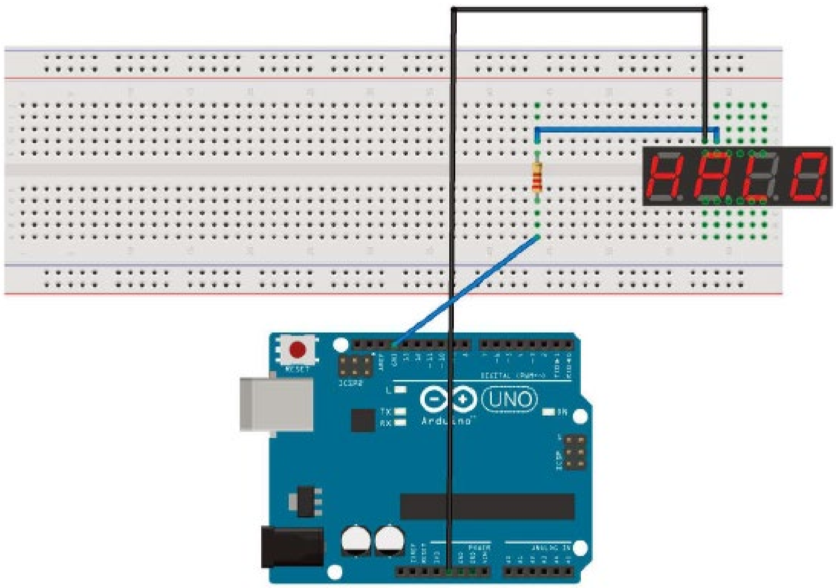
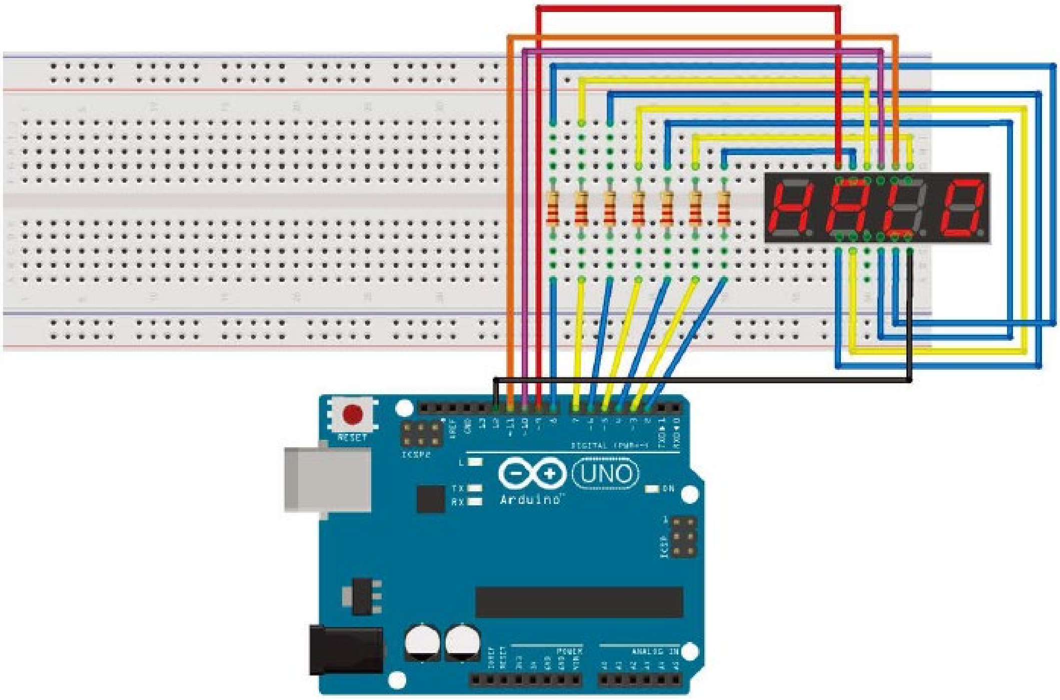


Figure 11.38 Structure of Using 4 Digit 7 Segment

Compose the circuit as follows: if the LED corresponding to ~~an of~~ the leftmost 7-segment is turned on, it is a common anode.



To connect the 4-digit segment circuit, configure the circuit as follows. Connect pins a, b, c, d, e, f, and g of the 4-digit 7-segment to pins 2, 3, 4, 5, 6, 7, and 8 of the Arduino board through 220Ω resistors. Connect the 4-digit 7-segment COM1, COM2, COM3, and COM4 common cathode to pins 9, 10, 11, and 12 of the Arduino.




```
byte digits[10][7] = // cathode
{
{1,1,1,1,1,1,0}, //0
{0,1,1,0,0,0,0}, //1
{1,1,0,1,1,0,1}, //2
{1,1,1,1,0,0,1}, //3
{0,1,1,0,0,1,1}, //4
{1,0,1,1,0,1,1}, //5
{1,0,1,1,1,1,1}, //6
{1,1,1,0,0,0,0}, //7
{1,1,1,1,1,1,1}, //8
{1,1,1,0,0,1,1}, //9
};

byte seg_DP = 11, k = 0;
int num=0, num0, num1, num2, num3;
int delaySeg = 1, delayDigit = 1, delayTime = 1000;
unsigned long previousMillis = 0;

void setup() {
// put your setup code here to run once:
for(int i=4; i<16; i++)
pinMode(i, OUTPUT);
digitalWrite(seg_DP, LOW); // DP pin is always Off
}

void loop() {
// put your main code here to run repeatedly:
unsigned long currentMillis = millis();
if(currentMillis - previousMillis >= delayTime){
previousMillis = currentMillis;
Segment_counter();
```

```
}
switch(k)
{
case 0:
displayDigit(num3);
DIG_num(3);
delay(delayDigit);
clearSeg();
break;
case 1:
displayDigit(num2);
DIG_num(2);
delay(delayDigit);
clearSeg();
break;
case 2:
displayDigit(num1);
DIG_num(1);
delay(delayDigit);
clearSeg();
break;
case 3:
displayDigit(num0);
DIG_num(0);
delay(delayDigit);
clearSeg();
break;
case 4:
clearSeg();
delay(delayDigit);
break;
default:
break;
}
k++;
k = k % 5; // infinite loop between 0 and 4 ( 0->1->2->3->4->0...)
}

void displayDigit(int num)
{
for(int i=0; i<7; i++)
{
digitalWrite(4+i, digits[num][i]);
//delay(delaySeg);
}
}

void Segment_counter()
{
num++;
num3 = num/1000; // thousands place.
num2 = (num/100)%10; // hundreds place
```

```
num1 = (num/10)%10; // tens place
num0 = num%10; // ones place
if(num > 9999) num = 0;
}

void DIG_num(int n)
{
for(int m=0; m<4; m++)
{
if(m==n) digitalWrite(15-m, LOW);
else digitalWrite(15-m, HIGH);
//digitalWrite(15-m, LOW);
}
}

void clearSeg()
{
for(int i=12; i<16; i++) digitalWrite(i, HIGH);
}
```

CHAPTER 12

ICT for STEM and Innovation

In this chapter, you will learn the following:

12.1 Experiment with Measuring Electrical Current

12.2 Experiment with Electrification

12.3 Newton's Laws

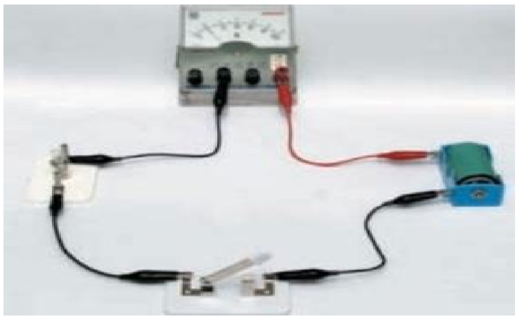
At the end of the lesson, students will be able to:

- Describe how to do experiments on measuring electrical current, voltage, solve the exercise using algorithm and resistance using ICT tools
- Indicate the value of electrical current, voltage, and resistance using ICT tools
- Possess a spirit of using ICT for learning Physics (formatting-should be on 1st page)

12.1 Experiment with Measuring Electrical Current

Discovering

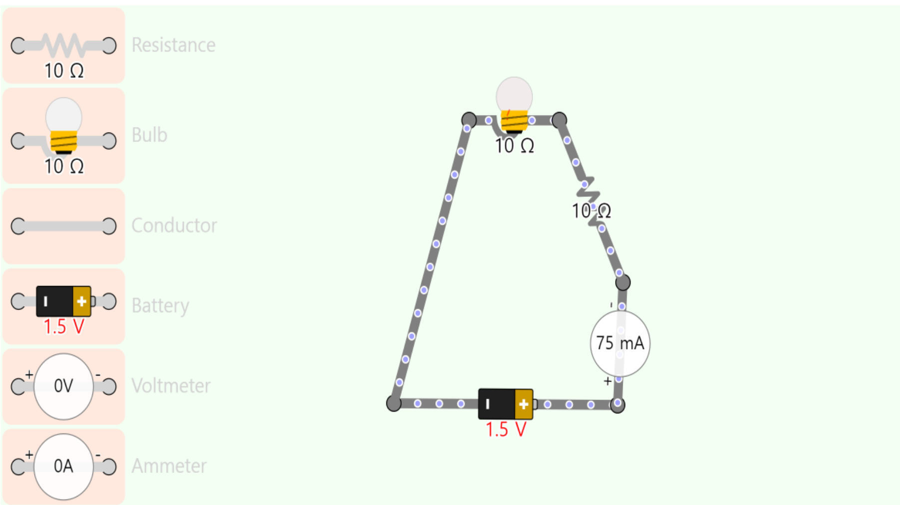
In order to turn on the light bulb, a device such as a battery and a wire is required. By connecting these devices to configure the electrical circuit, you can light it on the bulb. In order to keep the light on the bulb, the current must continue to flow. How can I measure the flowing current?



Analyzing

Measuring Voltage	What happens to the strength of the current as the voltage increases?
Measuring Resistance	What are the characteristics of the way the resistors are connected?

Practice 1



1. Access to the website www.javalab.org
2. Find a simulation called "Electric Circuit Simulator".
3. You can make the electric circuit you want by connecting batteries, wires, light bulbs,

voltmeters, and ammeters.

4. You can adjust the resistor value by clicking the resistor. (In the case of Android, press and hold for about 1 second, depending on the model.) You can adjust the supply voltage by clicking the battery. (In the case of Android, press and hold for about 1 second, depending on the model.)

Optional:

- Drag ‘Battery’ and drop where you want.
- Drag ‘Bulb’ and drop where you want.
- Use ‘Conductor’ to link the left side of ‘Bulb’ and ‘Battery’.
- Use ‘Resistance’ and ‘Ammeter’ to link the right side of ‘Bulb’ and ‘Battery’.
- Click ‘Resistance’ to adjust the value of resistance.
- Click ‘Battery’ to adjust the value of voltage.

Doing by Yourself

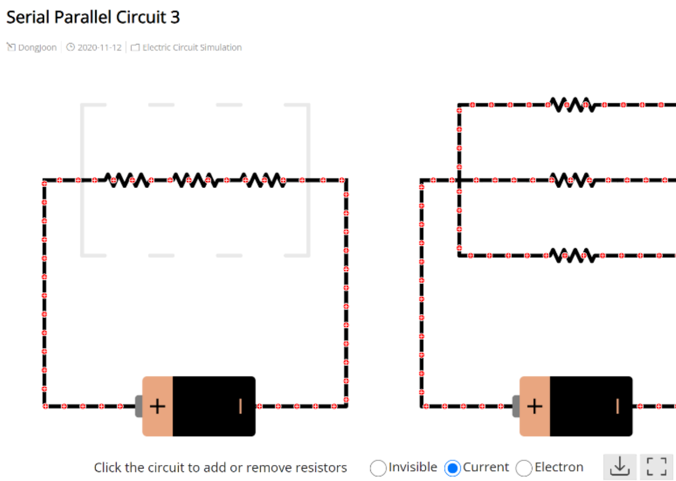
1. Click “Battery” and increase the value of Voltage by 1.5V. Measure the value of Current(mA) and write in the table (Resistance should be set as 10Ω).

voltage(V)	0	1.5	3.0	4.5	6.0
current(mA)					

2. Click “Battery” and increase the value of Voltage by 1.5V. Measure the value of Current(mA) and write in the table (Resistance should be set as 60Ω).

voltage(V)	0	1.5	3.0	4.5	6.0
current(mA)					

Practice 2



1. Access ~~to~~ the website www.javalab.org
2. Find a simulation called “Electric Circuit Simulator”.
3. Connect three resistors in series in the circuit on the left.

4. Observe how the speed of the current changes while removing the connected resistance one by one.
5. Connect the three resistors in parallel in the circuit on the right.
6. Observe how the speed of the current changes while removing the connected resistance one by one.)

Doing by Yourself

1. Let's summarize the characteristics according to the connection method of resistance. Write down in your notebook.

Serial connection	Parallel connection

12.2 Experiment with Electrification

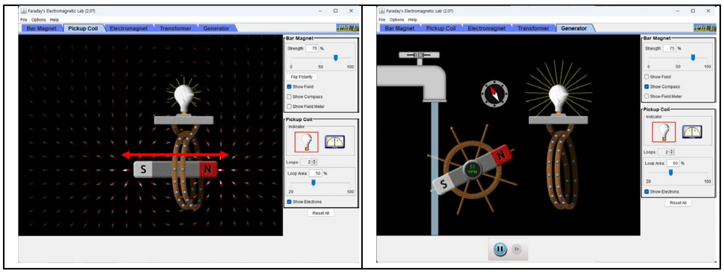
Discovering

Wind turbines generate electricity by rotating wings when the wind blows. In hydroelectric power plants, falling water turns turbines to generate electricity. In this exercise, let's find out how electric energy is created in a generator.

Analysis

Electrification	How can I turn on the light bulbs with magnets and coils?
Electrification in a generator	How does electrical energy come from a generator?

Practices



1. Access the 'PhET Simulations'.
2. Find an experiment called 'Faraday's Electromagnetic Lab'.

- Pickup Coil: use a magnet to change the level of brightness. You can try to change the level of brightness and observe the brightness of the light bulb using a magnet.
- Electromagnet: is a kind of magnet where the magnetic field is created by an electric current. The magnetic strength of an electromagnet can be easily altered by varying the amount of electric current and its polarity can be changed by varying the direction of the electric current.
- Transformer: Transformers are used to transfer current from one circuit to another without any physical contact between them and without changing the frequency or phase.
- Generator: change water energy to electrical energy. You can switch on the faucet and observe the change in light bulb brightness

Doing by Yourself

1. In the 'Pickup Coil', how do you use a magnet to make the bulbs turn on?
2. Compare
3. In the 'Generator', explain how electrical energy is generated in a generator.

Doing Together

1. In the 'Generator', how can we make a light bulb's brightness strengthen using a faucet?

Self-Evaluation

Items	Evaluation
I can understand and explain the core concepts I have learned at this time.	○○○○○
I will apply what I learn to real life.	○○○○○
I helped my friends to complete the activity successfully.	○○○○○

12.3 Newton's Laws

Discovering

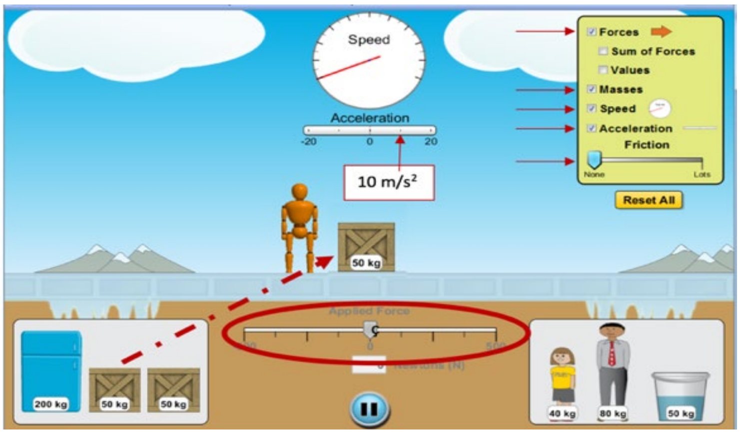
The movement of an object is closely related to the force acting on it. Whether a tennis player swings a racquet to hit the ball over the net or a defender stops the ball being driven by an attacker in a soccer match, both apply force to the ball and change the motion of an object. Let's examine the

relationship between the force and the motion of an object when a force is applied to it.

Analyzing

- How can I test Newton's first law of motion on video?
- How can I test Newton's second law of motion on video?
- How can I test Newton's third law of motion on video?

Practice 1

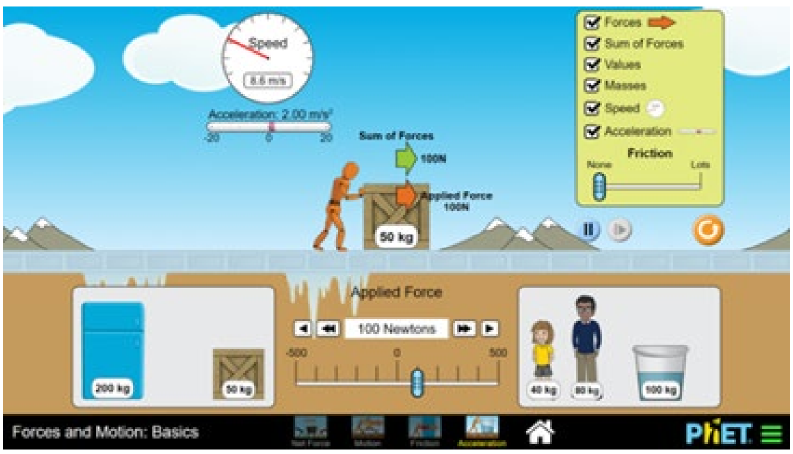


1. Access the 'PhET Simulations'.
2. Find a simulation called 'Force and Motion: Acceleration.
    - Acceleration: used to speed up. You can speed up to move the box.

Doing by Yourself

1. Use the simulation to answer each of the questions below (Use complete sentences to answer each question):
    a. How do you make the box speed up?
    b. How do you make the box move at a constant speed?
    c. Once the box is moving how do you make it stop?
    d. Once the box is moving how do you make it change direction?
    e. Describe the motion the box undergoes when you make it change direction.
2. Any change in motion is called acceleration. When does the box accelerate?

Practice 2



1. Access the 'PhET Simulations'.
2. Find a simulation called 'Force and Motion: Basic'.
   - Acceleration: used to speed up. You can speed up to move the box.

Doing by Yourself

Investigate the acceleration using Newton's second law (F=MA). Draw the table below in your notebook and fill in the blanks.

Mass (kilograms)	Force (Newton's)	Acceleration (meters/second^2)
40kg	100N	
50kg	100N	
80kg	100N	
100kg	100N	
200kg	100N	

1. What happens if you increase mass?
2. Was your prediction correct? Explain it in your notebook.

Summary

In this chapter, you have learned the following:

1. **Relationship between voltage, current, and resistance**: The intensity of the current flowing through the wire is proportional to the voltage and inversely proportional to the resistance.
2. **Serial connection:** When two resistors are connected in a series, the flow of each current is slower than that of one resistor.
3. **Parallel connection:** When two resistors are connected in parallel, the flow of each current is equal to the speed at which the current flows when one resistor is connected.
4. **Principle of generator:** When moving a magnet around the coil, the magnetic field passing through the coil changes and current flows through the coil.
5. **Wind Power generator:** Wind Mechanical Energy → Electrical Energy
6. **Water Power generator:** Water Mechanical Energy → Electrical Energy

Newton's Laws of Motion

a. **Newton's first Law of Motion (Law of Inertia):** An object remains at rest or moving at a constant speed unless a net force acts on it.
b. **Newton's second law of motion:** When a force acts on an object, the object will accelerate in the direction of the net force, and the acceleration a is proportional to the net force F acting on the object and inversely proportional to the mass m. Expressing this as a formula, $a=\frac{F}{m}$, that is, F=ma.
c. **Newton's third law of motion (law of action and reaction):** If object A exerts a force on object B, object B also exerts a force of the same magnitude and opposite direction on object A.

Questions

1. Let's summarize the similarities and differences between the first two experimental results. Let's write it down in your notebook.

Similarities	Differences

2. Let's explain the relationship between voltage and current.
3. Look for electrical appliances with multiple resistors and see how they are connected. Let's write it down in your notebook.

Electric appliances using serial connection	Electric appliances using parallel connection

4. When a magnet is moved around the coil, (………..) flows through the coil.
5. In a generator consisting of magnets and coils, (………..) energy is converted into electrical energy.

Exercises

1. Write your answers to all the above questions by using an OpenOffice Writer application and prepare them nicely.
2. Send the answers attached to your teacher by email.
3. Or follow instructions from your teacher (i.e., : "Just take a photo of your notes and send it to your teacher's telegram via mobile phone").

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KOICA
Korea International Cooperation Agency

Korea National University of Education