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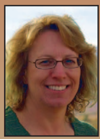
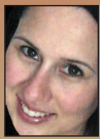

"When choosing tools for an educational makerspace, begin by considering the purpose of the space. This idea appears obvious, yet it is anything but obvious."

# The Environment and Tools of Great Educational Makerspaces

## Part 2 of Making an Educational Makerspace

R. STEVEN KURTI, DEBORAH KURTI, AND LAURA FLEMING

Great educational makerspaces inspire students to own their learning and deepen their thinking by exploring the world with all their senses. In a makerspace designed for independent exploration, curious students tinker and iterate their way through projects inspired by the space.

A great educational makerspace motivates more questions than answers because asking the right questions leads to deeper understanding. Such lessons are not learned in a vacuum, and when independent exploration is the goal, the design of the space and the choice of the tools are mission critical.

In the first installment of this three-part series, we discussed the philosophy of educational makerspaces. In this second installment, we will explore the look and feel of the environment and the selection of tools to inspire and equip makers to tinker, create, and invent. Innovation is fundamentally an inspired activity, and the right environment has the potential to inspire new thoughts and creative endeavors.

When choosing tools for an educational makerspace, begin by considering the purpose of the space. This idea appears obvious, yet it is anything but obvious. We would expect that the space and tools would be mostly technical in nature, yet evidence suggests that we should challenge our beliefs about creative, innovative thinking and the environments in which that thinking is fostered.[1] Educational initiatives often encourage exploration of STEM subjects (science, technology, engineering, and mathematics) to encourage creativity, but the energy to propel creative journeys remains conspicuously absent in many programs. The power comes by adding one simple aspect that has been too lightly discarded from our educational environments: art, the A that drives dry STEM programs to STEAM ahead.

A full treatment of integrating art and nonlinear thinking in STEAM subjects is beyond the scope of the present article, but a few words are warranted. Recent research suggests that the best scientists and technical innovators actually have an inseparable creative component to their methods of problem-solving.[2] For instance, Einstein, who is probably the most iconic physicist of the twentieth century, was sought after in his circle of influence as a violinist and had a multisensory grasp of physics rather than a methodical mathematical approach. Another physicist, Richard Feynman, who was awarded the Nobel Prize for his contributions to the field of quantum electrodynamics, has extensive anecdotes in his autobiography describing his love of drawing.[3]

Without going into the myriad of examples, we can hypothesize that quantum leaps in technical achievements begin as nonlinear thinking, which may not initially be logically derived. Major breakthroughs seem to occur through creative processes and are subsequently translated into words, equations, and diagrams through methodical processes. In effect, the most brilliant minds often teleport light-years ahead of others because they are not confined by linear pen-and-paper thinking. These creative processes are certainly not well understood, but studies are beginning to indicate a correlation between creative, artistic pursuits and the best technical minds, such as those of many Nobel laureates.[4] With this perspective in mind, let us consider the physical environment for an educational makerspace.

### CHOOSING AND ORCHESTRATING THE SPACE

The physical format of a makerspace is often overlooked but very important. Reflect on the most inspiring spaces you can recall. Such spaces are open, often filled with light, and awaken the senses. The awakening may arise as a result of beauty, quirky juxtapositions, or simply from empty space filled with possibilities. No matter the reason, the space should feel *inspiring*. This is a great opportunity to distinguish the makerspace from other spaces in the school or larger community by making it unique, inviting, and compelling.

The most important guiding principle is the interest of students. Due to the learner focus of a makerspace, it is absolutely critical to take into account the interests of the targeted population. For instance, it may be found that there is a high interest in textile-based projects among the student population due to the proximity of the school to a high-fashion district. Alternatively, students might be interested in robotics if many parents are working in technical fields such as engineering. There may also be strong pull among the student body for computer-gaming-based projects if there are many students who spend significant amounts of time playing online games. The tools chosen for the educational makerspace may not be able to completely indulge all students' interests but should have enough overlap to pique a significant natural curiosity.

Guided by the interests already inherent in the student population, the design and tools chosen for the makerspace will be relevant and inspiring. As mentioned previously, student ownership of the educational makerspace is the primary goal. Projects pursued by the students should arouse their curiosity and fill their thoughts even when they are not in the space. In this way the natural process of planning, building, and refining will be the best instructor, and with curiosity as a guide, education will extend beyond the brick and mortar environment and reach far into the future.

## SELECTING SPACE

The space should be open and invite exploration with areas designed to hook students visiting for the first time, as well as space for successively complex creativity. The best way to invite such a range of engagement is to allow for maximum flexibility. Thus an open space with few walls is an ideal environment, but other spaces may work well as long as they are easy to rearrange. Experience has also taught us that having more space invites more possibilities. Avoid cramped spaces if possible—creativity needs room to grow.

Other practical considerations include finding or creating space with all the right utilities. Make sure the space has plenty of electrical outlets to reduce or eliminate extension cords. Good network accessibility is also important. If the tools involve messy pursuits, the inclusion of sinks, easily cleaned work surfaces, and hard floors will be important.

Many other admonitions regarding space could be given, but let this word guide you: inspire! Inspiration need not be expensive. An age-old favorite is a warehouse look, which can be accomplished with pallets from the local hardware store, shipping crates, and an open floor plan. Ideas abound, but if you find yourself stuck, ask an art teacher to read this article. He or she will know what to do.

## OUTFITTING FOR ENGAGEMENT

Most great inventions start from a seed of inspiration. Good makerspaces need example projects, art to spark the thinking, and objects designed to elicit curiosity. Invite students, educators, parents, and local enthusiasts to bring creations to display. Create regular events to share compelling projects. Put up art that stirs the soul and photos that invite students to solve challenges facing their community, country, and world. Paint deep thoughts and questions on the wall. Place a large, flat-panel monitor with a question or contemplation for the day, or perhaps a video designed to stir up action. No matter the approach, engage students to solve their own problems, create their own art, and change their world. Encourage them to aim high, and even attempts that fall short will be amazing.

# BOOKMARKIT

SARA CATHERINE HOWARD

### JUNIOR NONFICTION

## DOES IT HAVE TO RHYME?

**Footprints on the Moon: Poems about Space** (Read! Explore! Imagine! Fiction Readers: Level 2.6). Selected by Mark Carthew. Teacher Created Materials, 2014. 28p. LB $13.15. 978-1-4807-1709-1. Grades K-3. Teacher Created Materials presents this collection of brief poems by well-known poets that are grouped as paired fiction/non-fiction within the theme of space adventures.

**Pucks, Clubs, and Baseball Gloves: Reading and Writing Sports Poems.** (Poet in You). Jill Kalz, ed. Picture Window Books, 2014. 32p. LB $22.00. 978-1-4795-2196-8. Grades 2-4. This new series introduces poetry writing, as well as some clever poems. For example "The Pole-Vaulter" not only uses metaphors, but describes how metaphors work. The back matter offers activities for getting started, a glossary, and read-more suggestions. Other books in the series include nature poems, nonsense poems and friendship poems.

Macken, JoAnn Early. **Read, Recite, and Write Free Verse Poems** (Poet's Workshop). Crabtree Publishing, 2014. 32p. LB $20.70. 978-0-7787-0408-9. Grades 3-6. Clever fact boxes, writing tips, and poems help the reader understand free verse. Additional titles in the series emphasize limericks, narrative poems and nursery rhymes. Additional books and websites, a glossary, and an index round out the title.

Raczka, Bob. **Santa Clauses: Short Poems from the North Pole.** Lerner: Carolrhoda Books, 2014. 32p. LB $12.71. 978-1-4667-071805-9. Grades K-3. Santa himself writes a December haiku poem-a-day until Christmas. The lovely, supportive illustrations show the readers side stories as the elves build toys, lick the cookie bowl, and watch Santa read "A Christmas Carol" to Mrs. Santa.

## GETTING STARTED

All the preceding information is about the ideal space, but remember, the best educational makerspace is a functioning space. Too much planning can be just as detrimental as too little planning. Because humans are involved, there are few right answers, but initial experiences are usually enough to guide the spacemakers to find the best arrangement. Aim in the direction of the target and adjust subsequent efforts based on the lessons learned. This approach of "Ready, Fire, Aim" derives from successful leadership philosophy[5] and is readily applied to the educational makerspace environment.

Practical considerations such as available space, budgets, and policies often set hard limits for the design of a makerspace, but we should never let limitations tell us what can or cannot be done. Limitations are merely an opportunity to express creativity to overcome them.[6] Both in the design of a makerspace and the use of the makerspace by young makers, limitations can be viewed in one of two ways: (1) as killing an opportunity, or (2) as an opportunity to overcome an obstacle by exercising creativity. Again, there is not space to fully explore this concept here, but our experience and the experience of others suggests that limitations do inspire greater creativity. So don't wait. No one can steer a parked car. The perfect environment may never exist! Go! Start! Do it!

## SELECTING TOOLS TO INSPIRE

To be effective in attracting the uninitiated maker, as well as keeping the attention of intermediate and advanced makers, makerspace tools should be chosen for maximum flexibility. In this section we will cover tools from simplest to most complex. Students will most likely explore the makerspace first using the simple tools and, as confidence grows, the more complex tools. When students first enter the makerspace, it will likely be out of curiosity, and they will naturally choose what feels comfortable. Thus for the beginning maker, tools that require little to no instruction are often the most attractive. Once student makers become more comfortable with the space, they will work with others to create complex projects with powerful tools, and these "cool" tools and projects will inspire them to go deeper.

## SIMPLE TOOLS

Choose beginner tools to inspire maximum curiosity with minimal explanation. Students instinctively know how to use Legos, clay, magnets, and other creative prompts. Photo booths and button making are examples of simple activities to ignite engagement. Tools with a short list of self-guided instructions or a brief creativity prompt are also appropriate at this level. These activities include take-apart stations with simple hand tools and a sheet that says, "See if you can take this apart. What's inside?," oobleck with an amplified speaker for an iPod, LittleBits electronics with a challenge task, or inexpensive blinking LEDs with a button cell battery and pipe cleaners for light-up art. With low barriers for engagement, students can stop in for five or ten minutes after their lunch period, play with magnets, and then run off to class. If the experience belongs completely to them, it will lead to independent exploration. This class of tools is strictly designed to hook students into the makerspace by tickling their curiosity while leaving them in charge of the experience.

## INTERMEDIATE TOOLS

The next step in student engagement occurs once students are ready to collaborate with others and learn more complex skills. At this level, tools such as 3D printers and scanners, 3D drawing programs, and simple electronics can be added. Due to the popularity of 3D tools and the accessibility of excellent simple electronic platforms, we will briefly discuss some practical aspects of choosing tools. The tools listed below were chosen because of their amazing flexibility to augment almost any project. Certainly there are many other possibilities other than the ones we will cover, such as machine tools, textile equipment, or cooking infrastructure, but the tools mentioned below are flexible and powerful. With them, a small makerspace on a budget will be able to equip students for maximum creativity. Thus, even though we cannot cover every possible tool, allow us to pull back the curtain to a wonderful world filled with possibilities.

## 3D PRINTERS

Choosing a 3D printer is likely one of the more important tasks in an educational makerspace these days. These printers have improved dramatically in the past few years, but not every one is well suited to educational environments. Thus it is important to consider the following.

*Usability*: The 3D printer should have good usability reviews. In an educational setting where most makers will be novices, a highly technical or build-it-yourself printer may not be appropriate, but there are several 3D printers on the market now that are quite simple to set up and use.

*Materials*: Check the price of refills. One of the pitfalls that some makerspaces have found is that they purchase a 3D printer, use up the materials that come with the startup package, and then find out that refills are quite expensive. It only takes a few moments to check on the cost of the refills for any given printer, and a cost of materials can range from $30 per kilogram up to several hundred dollars per kilogram. For the beginning makerspace, we recommend selecting a printer that uses materials at the lower end of this range.

*Tech Support:* Another commonly overlooked feature of 3D printers is the available support. Since personal 3D printing technology is so new, the technology still has some kinks and bugs to work out even for the very best printers, and that means most makerspaces are likely to experience broken parts within the first year of use. Unless the makerspace is staffed with an engineer, it will be important to have a good manufacturer's warranty for the first year while users are becoming familiar with the technology; and unless there are plans to upgrade printers every year, experience indicates that buying an extended warranty is almost always worth the money. A good affordable warranty will be about 10–20 percent of the cost of the product as a general rule. Check that the company has a long enough track record and enough company structure to actually service warranty requests for many years to come.

There are other less urgent considerations when purchasing a 3D printer, so look for good comparative reviews[7]. Because 3D printers are aimed at hobbyists with plenty of time to tinker rather than teachers who always need more time, consider carefully the effort it will take over the long term to keep the printers running. 3D printing technology is changing quickly. This is one area where seeking the help of experts may be warranted.

## DESIGN SOFTWARE

Along with a good 3D printer, a makerspace should have software for student makers to create their own 3D designs. To be useable with a 3D printer, the software should be able to export as an STL file, which most current programs will do. The following is a list of the major categories for 3D design software for educational makerspaces.

*Entry-Level Software:* A good starting software for student exploration is Google Sketchup. Sketchup is often used for architectural drawings, and with practice, other items can be made. There are several other easy-to-use beginner programs, such as 3DTin and the 123D Creature app. Each of these applications takes only a few minutes to start drawing independently.

*CAD Solid Modeling Software:* If students are interested in creating more complex engineering drawings, we recommend finding a CAD solid modeling software such as Cubify Invent, 123D Design, or TinkerCAD. A solid modeling program fundamentally creates parts as solid objects. One particularly powerful program is OpenSCAD, which uses computer coding to create 3D shapes and can be used in conjunction with InkScape to make extrusions. There are many other solid modelers on the market, and the best benchmark of how easy the software will be for students to use is to look up tutorials either online or bundled with the software. At the moment, the authors have not found a truly easy-to-use, quickly-rendering free solid modeler for engineering design for students, but we continue to search. In the meantime, prepare to pay a little for CAD software that is simple to use, and remember that even the simple CAD programs have a learning curve you should help students traverse.

*Artistic Mesh Modeling Software:* For artistic modeling, there are now software packages that allow students to interact with the 3D model as "digital clay." These programs fundamentally treat the models as a mesh surface made out of small triangles. This type of software is becoming more common; some examples are Cubify, Sculpt, Meshmixer, and Sculptris. There is also other powerful mesh-modeling software available, such as Blender, Rhino, 3DS Max, and Maya, but spacemakers should try them out and compare the learning curve and price against the value for students, since many of the current tools have a free "lite" version and a full-price featured version.

Along with these 3D software suggestions, we also recommend getting familiar with MeshLab or a similar mesh editor for fixing problems in your STL files when they occur. When choosing design software for your makerspace, we recommend having choices for students beginning with simple beginner 3D modeling, 3D CAD solid modeling software, and 3D software aimed at artists. It is always recommended that spacemakers use the software themselves prior to introducing it to students. No matter the tools, experience tells us that students graduate very quickly from simple tools to more complex ones as long as tutorials and other student experts are available, so be prepared to adapt quickly.

## 3D SCANNERS

To augment designs or simplify the design process, student artists may need 3D scanning capability such as the Matter and Form 3D scanner, the Structure Sensor, or the Makerbot 3D scanner. These scanners will create a 3D model from an available object and return a file that can be 3D printed or modified in 3D design software. Students should be exposed to object scanning because it is the companion technology to 3D printing. This is another area where expert advice may be helpful.

## ELECTRONICS

The last item in the intermediate class of tools is a good set of versatile electronics. In today's market, many of the projects students conceive will need interactivity. To get good interactivity without needing deep knowledge of the electronics, it is important to carefully select the platform for exploration. There are many possibilities available on the market today, such as Arduino, BeagleBone, and Raspberry Pi. However, it is the opinion of the authors that the Arduino platform is the largest and most broadly developed for education. It can be used by the most novice user to blink a simple LED, but it also has the horsepower to create a broad range of highly complex and interesting projects, including Geiger counters, robotics, and science equipment. While simple Arduino projects abound, the platform will continue to power student projects as the complexity grows. However, keep an eye on the interests of the students and be ready to introduce alternative tools when they are ready or when the projects demand different tools.

## ADVANCED TOOLS

More advanced tools should be added as student expertise increases. Due to the introductory nature of this article, the suggestions for this class of tools will be much briefer. As students grow in their maker skills, introducing them to more powerful 3D tools, such as more capable CAD packages, will greatly enhance their designs. Another possible augmentation would be more involved electronics platforms, such as Raspberry Pi, which is excellent for applications requiring video. Raspberry Pi uses a small Linux operating system capable of web browsing, playing audiovisual media, and many other functions that are much more complicated to perform on platforms such as the Arduino.

At this level, makerspaces should also include a much more extensive range of electronic components, such as kits containing resistors, capacitors, integrated circuits, switches, and other solid state components. It would also be useful to keep a range of DC motors, stepper motors, and other actuators for making interactive projects. With more advanced student makers, the makerspace may also want to consider devices such as phones, tablets, computers, and networked devices. As projects become larger, students may also need the additional capability of a laser cutter or CNC router for larger enclosures, artistic endeavors, and possibly alternative materials. There are certainly thousands of other tools that could be listed in this category, but only a few are mentioned because by this point the spacemakers and students will be the most appropriate sources for determining tool selection.

We would be remiss if we did not mention that as the student projects become more complex, the spacemakers should begin to recruit mentors for student projects. This will become ever more necessary as the students' skills increase. It may be helpful to connect with experts such as the authors or other educational makers. However, it is not necessary for spacemakers to be experts themselves. It is their job to create a fantastic environment, provide the tools, and then get out of the student's way. In a great educational makerspace, the students will grow to be the experts and will seek out their own answers.

## CONCLUSIONS

By working to create an inspiring space and filling it with accessible and exciting tools, the spacemaker will have an excellent Petri dish in which to study the best ecosystem for growth. Yet there are a few roadblocks that should be removed before getting started. First, avoid the fallacy that one should wait until the prices fall and stabilize. This argument is akin to saying, "Let's not buy food until the prices come down." This is a recipe for starving the creativity of your students. Make the space, get the necessary tools to feed student innovation, and resist looking into the crystal ball for future prices.

Next, remember to involve stakeholders in choosing space and tools. Students will want to know that you are considering their interests. Educators are likely to want specific types of technology that will complement their classroom interests. However, there is only so much data that can be collected before the hunger to make things should begin to overwhelm the need to get everything right.

This brings us to the final and most important roadblock to overcome: inertia. Objects at rest tend to stay at rest. Chances are high that some policies will stand in the way, space will be hard to obtain, and the budget for tools will be almost nonexistent. If this seems daunting, it would be a good exercise to read a biography of George Washington Carver or Winston Churchill. Return with the necessary inspiration to start something regardless of the obstacles. No great endeavors occur without effort, and creating an educational makerspace is no exception. The first space will probably be small. The first tools will probably be cheap or free. However, as mentioned earlier, the best makerspace is a functioning one. Find a team of supporters to help overcome the inertia and get started. You will likely find yourself in the role of chief encourager and evangelist, but the results will be well worth the effort. As the proverb says, "The best time to plant a tree was twenty years ago. The second best time is now."

## NOTES


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