SCOPES-DF

Scaling a Community of Practice for Education in STEM through Digital Fabrication

Reflection and Playbook

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Executive Summary

The Fab Foundations' Scaling a Community of Practice for Education in STEM (science, technology, engineering, and math) through Digital Fabrication (SCOPES-DF) is the result of calls from educators and the philanthropic community for high-quality K–12 digital fabrication education. SCOPES-DF is a global research and development project that leverages the Fab Lab Network, the Maker Movement, members of academia, and educators across the world to bring the potential of digital fabrication into the classroom to catalyze and deepen STEM learning. Therefore, the goals for the *SCOPES-DF Playbook* are to: (1) introduce current theories that inform how K-12 students learn about the tools and processes of digital fabrication; (2) present Fab tools and practices at the secondary school level in a way that would be both accessible to students and aligned to mandated state standards (e.g., Common Core or Next Generation Science Standards – NGSS); (3) increase the accessibility of digital fabrication for all students, especially those who are members of underrepresented groups; and (4) provide the framework for evaluation to study the impact and full potential of digital fabrication in K-12 learning environments.

The Scaling a Community of Practice for Education in STEM through Digital Fabrication Reflection and Playbook (referred to throughout the document as *Playbook*) presents an emerging framework that can be used to integrate digital fabrication fluency and competency throughout primary and secondary schools both in the United States and throughout the world. It is written in response to the pressing need to provide academic coherence to the rapid growth and integration of artifact creation and digital fabrication concepts into K–12 classrooms. During the past decade, the Maker Movement in Education, designated as "Tinkering," "Makerspaces," "FabLearn Labs," "Design-Make-Play," "Maker-Centered Learning," or Fab Labs, has increased usage of digital fabrication devices, such as 3D-printers, laser cutters, or milling machines in U.S. classrooms. As noted in a 2013 paper by Sherry Lassiter, President and CEO of the Fab Foundation and a team of co-authors at the Teaching Institute for Excellence in STEM:

> *There are examples of formal education integrating digital fabrication into project-based learning environments, with great success…. Unfortunately, these examples are the exception, not the rule. The lack of a national consensus regarding standards for teaching or learning with digital fabrication in the classroom severely inhibits formal institutions from adopting a potentially powerful toolset for engaging students in STEM and the arts and providing hands-on, authentic learning opportunities in a transdisciplinary learning environment. Due to this, adoption of digital fabrication in formal education has been inconsistent. Digital fabrication continues to be perceived as an after-school opportunity rather than a formal educational platform for STEM learning. Formal education, while pulling for this transdisciplinary platform, has not yet devised large-scale strategies to empower and support educators in implementing digital design and fabrication in the classroom.*

This *Playbook* was not written in a vacuum. We understand the serious constraints under which school districts are operating and the uphill battle that digital fabrication integration faces in light of other teaching priorities, as well as time and budget constraints. There are also time and budget constraints. Despite these realities, we hope that the *SCOPES-DF Playbook* will serve as a catalyst for widespread discussions and the initiation of many pilot projects that spearhead the evolution of K–12 digital fabrication integration. K–12 educators are only one of many stakeholder groups who must come together to expand student access to high-quality digital fabrication learning. However, as they are the ones who will play the crucial implementation role, this *Playbook* is designed to help them do so. The objective is to provide educators with actionable ideas that can allow high-quality digital fabrication integration in K–12 formal education spaces to gain momentum at a thoughtful and strategic scale.

As a result, this *Playbook* primarily targets K–12 educators and is designed for formal education classrooms. However, given the growth of accountability for extended learning as well as out-of-school-time educators, it will also be useful in informal education spaces. We invite you to read the SCOPES-DF Playbook, and hope that you would be motivated to take part in this discussion. More information about ongoing activities related to this effort can be found on the SCOPES-DF website at www.scopesdf.org.

Fab Labs
Making
Tinkering makerspaces Design-Make-Play
Digital Fabrication

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INTRODUCTION

The Fab Foundation is a U.S. non-profit 501(c)(3) organization that emerged from the Massachusetts Institute of Technology (MIT) Center for Bits & Atoms (CBA) Fab Lab Program. The Foundation's mission is to provide access to the tools, knowledge, and financial means to educate, innovate, and invent using technology and digital fabrication to allow anyone to make (almost) anything. As noted by Professor Neil Gershenfeld, Director of CBA: "The first digital revolution was in communication...The second digital revolution was in computation...We are now living through the third digital revolution, in fabrication. The first two revolutions rapidly expanded access to communication and computation; this one will allow anyone to make (almost) anything (Gershenfeld, et al., 2017, p. 17)."

The Foundation's decade of experience with fabrication has established beyond doubt the possibilities of digital fabrication. The SCOPES-DF project goal is to extend this knowledge within elementary and secondary classroom environments. By building on fundamental notions of "learning-by-making," K–12 students are provided learning opportunities to make meaningful digitally fabricated artifacts the creation of which requires acquiring knowledge in the component areas of design, mathematics, and engineering, physics, electronics, computation, and materials sciences, as well as other subject areas including English Language Arts and Social Science.

SCOPES-DF is the first project of its kind, in that its aim is to specifically develop effective pathways and resources for using digital fabrication in K–12 education. The Fab pedagogy is a student-centered approach to learning that encourages engagement, curiosity, creativity, collaboration, problem solving, critical reasoning, and design thinking. These objectives are aligned with the existing and emerging locally-led, nationally recognized STEM school initiatives, ranging from individual K–12 schools and district-level programs to more comprehensive regional STEM ecosystems.

Before discussing the *SCOPES-DF Playbook* itself, it is important to explain the context. The *Playbook* seeks to provide observations from lessons learned during the 2018 Experiential Leadership Cohort, a year-long engagement focused on digital fabrication professional development with two schools and 14 educators. An important inquiry is to highlight conceivable elements of effective K-12 digital fabrication integration. On the surface, this might appear to be a simple question. However, it is complex because the answer is reliant upon our beliefs and values about two things: (1) how we view learning, and (2) how we view the role of digital fabrication in the K-12 learning process. Digital fabrication in the realm of K-12 education refers to its meaningful implementation with the overarching goals to:

1. Promote appropriate digital fabrication technologies to enhance and support instruction and standards-based curricula.
2. Facilitate and support collaborative digital fabrication-enriched learning environments.
3. Facilitate use of digital fabrication to enhance instructional methods aimed at developing higher-level thinking, decision-making, and problem-solving skills.
4. Provide opportunities for teachers, students, and school leadership teams to take advantage of the Fab Lab Network and its extensive expertise with digital fabrication tools and procedures.

To reach these goals. The SCOPES-DF project focused activities in three areas of work: (1) a website platform that houses digital fabrication lessons for educators to share; (2) a leadership cohort of educators to co-design and develop content; and (3) an evaluation strategy to measure potential impact. In the following pages, we have organized key learnings and reflection from our work into individual plays. Each play is intended to highlight a key approach and deliverables developed from our work to date. We will proceed in this *Playbook* by: (1) revisiting some common learning theories to determine how they might influence our perspective on the role of digital fabrication in learning; (2) exploring the beliefs and values that individuals and institutions might apply when evaluating digital fabrication use in the classroom; and (3) providing an overview of some common Fab tools and processes used to help teachers better understand digital fabrication integration.

Play #1: Theoretical Background

Epistemology is a branch of philosophy concerned with the nature and scope of knowledge. It seeks to answer the following basic questions:

- **What is knowledge?**
- **How is knowledge acquired?**
- **How do we know what we know?**
- **What kind of knowledge is most important?**

The two dominant theories that shape K-12 conversation surrounding the nature of knowledge and how a student learns about the tools and process of digital fabrication are constructivism and constructionism. Each of these theories has been studied and written about at length and it is beyond the scope of this *Playbook* to fully outline the debates between the two. Rather, we will provide an overview of each of these theories, what each entails, and, based on lesson learned working with the cohort schools, what each might mean for teaching and learning with digital fabrication. For a detail review see, Edith Ackermann's *Piaget's Constructivism, Papert's Constructionism: What's the difference?* Available at http://learning.media.mit.edu/content/publications/EA.Piaget%20_%20Papert.pdf.

PIAGET CONSTRUCTIVISM

Constructivism is a paradigm within the broader scope of epistemology. It is guided by a learning or meaning-making theory that offers an explanation of the nature of knowledge and how human beings learn. According to its postulates, individuals create or construct their own new understandings or knowledge in two ways: (1) through the interaction between what they already believe and (2) the ideas, events, and activities with which they come into contact. One of the most prominent constructivist theorists, Jean Piaget (1896–1980), has in his lifetime made wide-ranging contributions to the practices of education and K-12 curriculum development.

According to Piaget, student-learners develop knowledge directly by experiencing things and by reflecting on the consequences of such experiences. Most importantly, they learn actively through cognitive processes, constructing their own understanding of the world around them. Piaget therefore rejected the subject-centered approach to teaching, proposing that focus should be on the student-learner, who should be permitted to play an active role in the construction of his/her knowledge. Lev Vygotsky (1896–1934) extended the aforementioned constructivist postulates by introducing the notion of social constructivism, placing a particular emphasis on the idea of "situated learning." This mode was later espoused by Lave and Wenger (1991), who posited that learning is contextualized in social and cultural interactions. Their main argument is that knowledge cannot be taught in an abstract manner and, to be useful, it must be situated in a relevant or "authentic" context.

In other words, student-learners should not be treated as passive receptors of knowledge provided by the instructor. Rather, they should be permitted to construct meanings for concepts in real-world settings. The teacher is a guide, facilitator, and co-explorer that encourages learners to question, challenge, and formulate their own ideas, opinions, and conclusions.

Elements of Piaget's theory of cognitive development can be found in school curricula across the globe. For example, the most recently implemented curriculum reform in Hong Kong embraces Piaget's approach to teaching and learning (Curriculum Development Council, 2001). Constructivist pedagogies in the Chinese classroom that have resulted from this change include:

- **Nature of learner:** Student-learners should be seen as unique individuals, as the unique nature of each student is an integral part of the individual learning process.
- **Responsibility for learning:** The active role of student-learner in the learning process should be emphasized, focusing on looking for meaning.
- **Learning motivation:** Student-learner motivation should be developed through authentic experiences in handling problems.earners gain confidence and incentive to embark on more complex challenges, thus developing intrinsic motivation to succeed.
- **Role of the teacher:** Teachers should ask probing questions, support students in the learning process, provide guidelines, and create an environment for each learner to arrive at conclusions, while also challenging learners.
- **Interaction:** Teachers and student-learners should learn from each other and should approach each learning task as an interface through which they can develop awareness of the other's viewpoints as well as examine their own standards and values.
- **Collaboration:** Student-learners should be encouraged to collaborate in order to arrive at a shared understanding of truth in a specific field. The teachers should focus on "scaffolding," as this allows learning to extend beyond the limitations of physical maturation to the extent that the development process lags behind the learning process.
- **Context:** The context in which learning occurs must be seen as central to learning, which should always be directly relevant to application. Context should acculturate student-learners into authentic and complex practices through activities and social interaction.
- **Assessment:** Assessments should be conducted regularly. Moreover, they should always be a two-way process involving interaction between teachers and student-learners. Assessment and evaluation are inextricably linked with the learning process, as the results allow the learning achievements to be measured and the quality of the learning experience to be improved.

Working with the 2018 Experiential Leadership Cohort, the SCOPES-DF model supported the constructivist learning process in two ways: (1) by making abstract concepts and facts more grounded in personal digital fabrication experiences; and (2) by allowing the learning experience to be differentiated for individual learners. Highlights included:

- Provide teachers and students with real-world experiences, as they have to work in teams to perform and finish digital fabrication projects such as pinball machines, biomimicry book shelters and wearable technology.
- Design reviews and presentations that solicited constructive feedback from students,teachers and administrators. The presentations requires teams of students and teachers to address problems or illuminate big ideas.
- Design & build sessions that lead teams through design thinking exercises, sketching and prototyping, digital fabrication and assembly tasks. Teams are required to show working electronics and other components in their designs.

Teachers were encouraged to replicate projects (e.g., units and semester-long capstone projects) that help students incorporate multiple STEM theoretical situations when designing and developing their own solutions.

PAPERT CONSTRUCTIONISM

As a precursor to K–12 digital fabrication integration, the concept of constructionism was first advanced by Seymour Papert, who Martinez and Stager (2013) described as “the father of the maker movement.” A mathematician, co-creator of the Logo programming language, co-founder of the Artificial Intelligence Lab at MIT, and a founding faculty member of the MIT Media Lab, Papert advanced the notion of what has become known as “active learning.” Papert’s theory suggests that learning is most effective when the activity involves making of a meaningful artifact-- something shareable (Papert 1991). This type of hands-on/minds-on discovery-based learning is critical as a standalone. It is also critical as a conduit to learning STEM subjects as well as important 21st century skills (e.g., such as problem solving, critical thinking, creativity, innovation, collaboration, and communication). Inspired by the work of Papert, Mitchel Resnick’s Lifelong Kindergarten research group at MIT Media Lab developed a creative learning strategy based on four elements commonly referred to as the four P’s of creative learning:

- **Projects.** People learn best when they are actively working on meaningful projects – generating new ideas, designing prototypes, and refining iteratively.
- **Peers.** Learning flourishes as a social activity, with people sharing ideas, collaborating on projects, and building on one another’s work.
- **Passion.** When people work on projects they care about, they work longer and harder, persist in the face of challenges, and learn more in the process.
- **Play.** Learning involves playful experimentation – trying new things, tinkering with materials, testing boundaries, taking risks, iterating again and again.

The four P's are strongly aligned with the Constructionist approach to education. The approach emphasizes the value of learners playfully creating personally-meaningful projects in collaboration with peers (Kafai and Resnick 1996). Sherry Turkle, MIT Professor of Social Studies and Technology, advanced this discussion by researching the social and psychological dimension of technological change. She argues that:

> *The hard jobs in education [are] getting children to love learning, to find something in learning that fits with their life and experience and where they can find meaning in their own lives and love learning this. To see how learning can give them a better life is very important. If students don't think learning can give them a better life, there is no reason to learn.* https://www.pbs.org/wgbh/pages/frontline/digitalnation/interviews/turkle.html

Professor Turkle advocates for teaching children social and emotional skills and the pace of conversation for empathy, community, and creativity (Turkle 2015). Gary Stager, another Ph.D. student of Papert, identifies eight "Big Ideas Behind Constructionist learning for K-12 education:

- **Learning by doing.** We all learn more effectively when learning is integrated into something we find really interesting. Knowledge acquisition is further enhanced when we use what we have learned to make something we really want.
- **Technology as building material.** It is based on the premise that, a lot more interesting things can be made using technology, while also learning a lot more in the process of creation.
- **Hard fun.** We learn most effectively and work most productively if we enjoy what we are doing. However, fun and enjoyment should not be seen as synonymous with "easy." The best fun is hard fun.
- **Learning to learn.** Many students believe the only way to learn is by being taught. This is false and is often the primary reason for failure in school and in life. Nobody can teach you everything you need to know. Learners must be proactive and open to the learning styles best for them.
- **Taking time – the proper time for the job.** Many students are used to constantly being told what to do while in school. Every five minutes or every hour, they simply follow commands, such as do this, then do that, now do the next thing. If someone is not telling them what to do, they get bored. This process does not reflect real life. To do anything important you have to learn to manage both tasks and time for yourself. This is the hardest lesson for many of our students.
- **You cannot get it right without getting it wrong.** This idea is most important. Nothing important works the first time. The only way to get it right is to look carefully at what happened when it went wrong. To succeed, you must not be discouraged by failure and should be given the freedom to goof on the way.

- **Do unto ourselves what we do unto our students.** We are learning all the time. While we may have gained extensive experience working on similar projects, each one is different. Thus, when embarking on a new initiative, we should not have any preconceived ideas of how the process will evolve or what the outcome should be. We should enjoy what we are doing, but should expect the progress to be hard. We must also take the time required to get each project right. Every difficulty we run into is an opportunity to learn. The best lesson we can give our students is to let them see us struggle to learn.
- We live in a **digital world** where knowing about digital technology is as important as reading and writing. (For a full discussion, see Gary Stager, The Daily Papert, http://dailypapert.com/eight-big-ideas-behind-the-constructionist-learning-lab/

One of the most effective way to teach within the *Papert Constructionism* framework is to have students construct artifacts in the outside world that support and reflect their classroom construction of Common Core/NGSS knowledge.

APPRECIATIVE INQUIRY

The SCOPES-DF model adopts the Appreciative Inquiry process for positive change-making. The intent is to ensure a commonly shared understanding and worldview for bringing digital fabrication into the formal K-12 environment. Sonya Pryor-Jones, Fab Foundation Chief Implementation Officer and certified Appreciative Inquiry Practitioner, facilitated this process with the SCOPES-DF staff and Leadership Cohort team using the 4-D model to discover the "best of what is," initiate dreaming about the "ideals of what might be," and assist with designing of "what should be," as discussed below.

DISCOVER: ***Appreciate—"The best of what is":*** In the Discover phase, participants make inquiries designed to reveal exceptionally positive moments. This is generally done through a paired interview process in which two group members focus on and share their experiences with instances of organizational excellence. Stories from the paired interviews are then shared with the entire group, allowing common threads and exciting new ideas for excellence to emerge.

DREAM: ***Imagine—"What might be":*** In the Dream phase, the focus shifts from the best of what is now to the imagining and envisioning of new possibilities. It is at this stage that action items can be formulated to bridge the gap between the best of "what is" and the school cohort visions of "what might be."

DESIGN: ***Determine—"What should be":*** In the Design phase, the SCOPES team begins to put into place the innovative actions needed to achieve the desired future. While specific strategies are developed during this phase, the learning process continues, leading to additional development, innovation, and modification.

DEPLOY: ***Ensure sustainability—"What will last":*** The Deploy phase represents both the conclusion of the Discovery, Dream, and Design phases as well as the beginning of the implementationof an "appreciative learning culture." (For complete discussion, see: What is Appreciative Inquiry? http://www.davidcooperrider.com/ai-process)

During our launch for the Leadership Cohort in December 2017, team members worked to identify provocative propositions, or "seeds," for each element of desired changes. The Affirmative Topic "How to integrate digital fabrication into the K–12 curriculum and learning environment" sets the parameters for the proposed elements. Seeds are stated in the present tense and future ideals are expressed as if they already exist. This Cohort Leadership strategic planning process resulted in the following seeds:

1. Reexamining the way we work (by building collective knowledge, connecting spaces/places, content, and methods).
2. Making all activities richly relevant and culturally embracing to learners.
3. Taking on the accountability for the learning standards as a resource vs. restraint.
4. Embracing the power of computational thinking for unique and new possibilities.
5. Legitimizing K–12 digital fabrication approaches, model, and progression of skills; scaffolding.
6. Cultivating the Community of Practice.

COMMUNITY OF PRACTICE

The term Community of Practice (CoP), based on seminal text *Situated learning: Legitimate peripheral participation* (Jean Lave and Etienne Wenger,1991), has become one the most important concepts in social or situated learning theory. In 2018, Etienne Wenger conducted a workshop with members of the SCOPES-DF team to explore aspects of implementing a K-12 community of practice for educators from an analytical perspective. The session addressed the following CoP disciplines:

- **The discipline of domain:** What is our partnership about? What is our learning agenda? What specific set of issues does it entail?
- **The discipline of community:** Who should be at the table so the partnership can make progress? What effects will their participation have on the trust and dynamics of the group? How do we manage the boundaries of the community?
- **The discipline of practice:** How can the practice become the curriculum? How can it be made visible and inspectable? What should participants do together to learn and benefit from the partnership?
- **The discipline of convening:** Who will take leadership in holding a social learning space for this partnership? How can we make sure that the partnership sustains a productive inquiry? Who are the external stakeholders and what are their roles? What resources are available to support the process?

As an outgrowth of the CoP session and lesson learned from our cohort team building, SCOPES-DF developed a "distributed" CoP model. This model connects Fab Lab Network members across international time zones. SCOPES-DF uses an online platform for creating, sharing and receiving standards-aligned lessons for K-12 schools and youth-centered educational environments. It has accomplished the following:

- Educators have an online forum for sharing knowledge and practices, in addition to sharing lessons.
- SCOPES-DF staff is curating, creating and testing new K-12 content and lessons. This includes a special collection of GE Brilliant Career activities, tied to standards and to classroom practice as developed in the Boston program.
- The website is showcasing additional lesson formats that display the range of instructional approaches around digital fabrication including open-ended projects and targeted, skills-based activities.
- Educators are able to remix existing lessons and submit them to the website's collection of open source materials.

In addition to open source resources, blogging opportunities support digital fabrication learning by giving teachers a platform for interacting, enhancing critical reflection, and collaborating with other educators and makers. Educators move from the periphery to more central roles in the Fab Lab Network as they develop from novices to experts. During the Fab 14 conference in France, we hosted a SCOPES-DF workshop with over 40 participants from the global community and learned that a number of educators across the United States (Oklahoma, the Carolinas, and Minnesota), Italy, Spain, and parts of South America had been using the SCOPES-DF website to garner credibility for their work with school-aged youth. During the next website development phase, we will intentionally grow the CoP through: (1) strategic outreach and promotion; (2) continued development and testing of new lesson content; (3) publication of best practices emerging from the project; and (4) the use of analytic tools to track our progress, specifically impact and reach.

Play #2: Accessibility and Accountability

EVERY STUDENT SUCCEEDS ACT

The recently adopted Every Student Succeeds Act or ESSA, guides state governments to "provide all children significant opportunity to receive a fair, equitable, and high-quality education, and to close educational achievement gaps" (SEC. 1001). For schools to meet the established mandates of ESSA, they must provide equitable opportunities in the following ways:

- Rather than focusing on imparting knowledge through rote-oriented instruction, ESSA mandates that education systems reflect 21st century learning skills such as creativity, collaboration and technology literacy. Through culturally relevant digital fabrication students gain these skills, beginning with novice-level tasks and progressing to more advanced projects.
- The new law therefore establishes a set of expectations that should be incorporated into standards and assessments that benchmark and measure students' higher-order thinking skills. It also emphasizes the need for providing relevant resources and embedded professional learning opportunities for teachers.
- Adoption of robust performance assessments that "tap into higher-order thinking skills—such as evaluating the reliability of sources of information, synthesizing information to draw conclusions, or using deductive/inductive reasoning to solve a problem—to perform, create, or produce something with transferable real-world application."
- Implementation of performance assessments in which students participate actively by contributing to their design and implementation, as well as present the results of their inquiries Adapted from Cook-Harvey, C. M., Darling-Hammond, L., Lam, L., Mercer, C., & Roc, M. (2016). Equity and ESSA: Leveraging Educational Opportunity Through the Every Student Succeeds Act. Palo Alto, CA: Learning Policy Institute. This report can be found online at http://learningpolicyinstitute.org/product/equity-essa.

CULTURALLY RELEVANT TEACHING

The changing demographics of classrooms in the United States make it incumbent upon teachers to know students' cultures. Culture plays a role not only in communicating and receiving information, but also in shaping the thinking process of groups and individuals. In order to improve cross-cultural interactions, teachers must learn not just the basic facts but even important nuances of their students' cultures (Hofstede, 1991). By embracing the sociocultural realities and histories of students through what is taught and how, culturally-relevant strategies help teachers negotiate classroom cultures with their students to reflect the communities where students develop and grow (Kozleski, 2010; Gay, 2000). The SCOPES-DF model recognizes that every student brings cultural knowledge, prior experiences, and performance styles to academic knowledge and intellectual tools. This legitimizes what students already know. This includes students from groups who, historically, are less engaged in STEM subjects such as girls and young women, African Americans, American Indians/Alaska Natives, and Latinos (NSF 2017).

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What is required of teachers is cultural competency or the ability to interact effectively with people of different cultures (Pratt-Johnson, 2006). This includes: (a) awareness of one's own cultural worldview, (b) attitude towards cultural differences, (c) knowledge of different cultural practices and worldviews, and (d) cross-cultural skills. Cultural competency is needed beyond race and ethnicity. Culturally-competent teachers also need to address issues of gender and disabilities. A working knowledge of these groups' cultures and values helps teachers tailor lessons and curricula so it is effective and appropriate for their students' needs. Digital fabrication provides teachers with ways to bridge students' cultural knowledge with academic knowledge through project-based learning. The SCOPES-DF model encourages the use of diverse, open source or free tools and methods that are inclusive of students' cultures --- ways of knowing and ways of being. SCOPES-DF highlights learning that is inclusive and meets the needs of diverse students. These include:

- Engaging girls in projects that are relevant to where they are in their lives, including the use and creation of wearable technologies (i.e., e-textiles). https://www.scopesdf.org/scopesdf_lesson/under-the-lights-wearable-device-designer
- Teaching students about Ethnic Chinese festivals and how to make their own custom lanterns to celebrate the Legend of Chang E. https://www.scopesdf.org/scopesdf_lesson/laser-cut-lantern
- Using a culturally-situated design tool to generate 2D designs and 3D models based on Ghanaian Adinkra symbols such as the ones in costumes worn in the Marvel film Black Panther. The SCOPES-DF Black Panther Collection of lesson plans best exemplify projects that are accessible, relevant and inclusive of diverse learners: https://www.scopesdf.org/black-panther-collection
- Helping students to be more aware of how visual symbols, color, and patterns are used in past and present social cultures and how they influence their personal identities. https://www.scopesdf.org/2019/01/31/otherness-film-and-digital-fabrication

The SCOPES-DF model exemplifies the instructional shifts, high-quality instructional materials, and student expectations ESSA requires. The model offers open-source standards-aligned lessons, project-based learning activities, and STEM-focused transdisciplinary capstone projects. Working with the cohort schools, the SCOPES-DF team offered insights and strategies to move these schools forward toward equity and cultural relevance. SCOPES-DF also provides access to the tools, knowledge and other resources to educate, innovate and invent using digital fabrication. This allows any student to make (almost) anything.

LEARNING STANDARDS

In U.S. classrooms, the emergence of K–12 digital fabrication is inextricably linked to the dynamics of education reform efforts that have been unfolding since the widespread adoption of Common Core State Standards (CCSS) and the Next Generation Science Standards (NGSS). The CCSS and NGSS blueprints for education in the 21st century aim to prepare students for college and careers in the rapidly advancing knowledge-based society. These reforms have brought major changes to formal education, particularly in the areas of curriculum construction, content, pedagogy, and assessment. Both CCSS and NGSS were produced in response to American schools' stagnant achievement levels relative to the rest of the world. Furthermore, they are benchmarked against standards in other top performing countries. As noted in the CCSS, a major goal is allowing educators to:

> *share a common language about what they want students to learn, and they enable development of high-quality materials that address the standards. They build upon previous experience with standards, both in the US and abroad, to create a focused, challenging, appropriate set of learning expectations that educators can interpret and implement locally through the curriculum, programs, and teaching methods they decide are best suited to their students.*

Analogous to the CCSS, there was a call for updating standards in science and in other disciplines. The National Research Council (NRC) directed the way with the publication of the *Framework for K-12 Science Education* (2012), a consensus document that described a research-based structure for how science education might be approached in the 21st century. The Carnegie Corporation of New York partnered with the NRC, the National Science Teachers Association, the American Association for the Advancement of Science, Achieve Inc. The final version of the NGSS was released in April 9, 2013 (the link to the NGSS website is: (https://www.nextgenscience.org). NGSS promote an engineering literacy perspective that views engineering knowledge as important for all students. According to NRC NGSS, *"represent a commitment to integrate engineering design into the structure of science education by raising engineering design to the same level as scientific inquiry when teaching science disciplines at all levels, from kindergarten to grade 12."* With the adoption of NGSS, the term "engineering design" replaced the term "technological design," consistent with the definition of engineering as a systematic practice for critical thinking and solving problems.

PROJECT-BASED LEARNING

Authentic learning experiences through contextualized and project-based learning (PBL) are given particularly strong emphasis with the CCSS/NGSS. Although it is important for students to learn a core set of Fab knowledge, they need to apply what they are learning by engaging in projects that foster skills in adaptive thinking, communication, collaboration, critical thinking, inquiry, problem solving and creativity, now prerequisites for student success in school and beyond. SCOPES-DF activities, grounded in project-based learning offer the following benefits:

1. A logical and well-structured approach to solving open-ended complex design problems through the design & build process implicit in digital fabrication.
2. A motivation for students to focus on applications of knowledge in authentic settings, rather than on theory only (i.e., lecture-based pedagogy) or on application only (i.e., subject content).
3. A powerful and exciting digital fabrication experience that can offer a unique perspective on STEM learning.
4. High-quality learning environment for all children, regardless of location, socioeconomic status, thinking style, racial background, or gender.

These approaches to teaching digital fabrication are aimed at imparting thinking skills and promoting deeper learning. The PBL method is particularly helpful to more marginalized students. It provides not only a more supportive environment for development, but also helps enhance individual and collective efficacy. SCOPES-DF project-based learning can be classified as inquiry-based learning in that it:

- Provides a unique opportunity for students to engage in the discovery of answers to questions; to work on formulating and testing hypotheses and finding solutions; and to actively participate in interactive discussions.
- Demonstrates how intangible ideas can be translated into relevant, understandable concepts pertaining to real-world situations.
- Helps students to understand abstract concepts in the context of an application and trains students to solve practical problems with no known solutions.
- Encourages students to think critically and to analyze various alternatives in order to arrive at a meaningful solution to practical open-ended problems.

One example comes from working with the 2018 Experiential Leadership Cohort in one of the SCOPES-DF cohort schools. The digital fabrication process of building a catapult supported the study of quadratic functions, Newton's Laws, and state mandated pre-Algebra learning standards. Under the guidance of the classroom teacher and SCOPES-DF team members, students were required to research, design and build either trebuchets or catapults. Digital fabrication is incorporated using design software, a laser cutter and a 3D carving machine or "Carvy". The benefit of digital fabrication is that it allows for multiple iterations in prototyping, and enables students to make adjustments to their launching device with better precision. Reflecting on their building process one group of student observed:

> When we first began working on our catapult, we designed a prototype out of cardboard. After testing its ability, we made some minor changes in TinkerCad and then began working in the Fab Lab to carve out our second model on the Carvey. In the beginning, our design did not work out as planned because we forgot to add tabs on the pieces, causing our pieces to pop out and chip in some areas. After fixing our mistake, we reviewed our design and moved onto the laser cutter and ShopBot. Following the advice we were told, we were able to successfully cut out and assemble our final catapult before the competition. The most challenging

catapult to build for us was definitely the ShopBot model, because it involved a much more complicated design program and it was much larger. Overall, this project allowed us to learn about the mechanics of catapults, different machines in the Fab Lab, and get hands on experience with designing and creating prototypes. (students Grace T. and Lauren B.)

PBL principles have been successfully implemented in several K–12 Fab Labs and makerspaces. As a departure for most PBL digital fabrication implementation, SCOPES-DF places a particular emphasis on Design Review. The SCOPES-DF model adopted a design review process including:

Desk Crits: Desk crits (short for critique) typically involve just the teacher/SCOPES-DF staff and one student or one group working on a single project. The intent of this review type is to be a brief and casual working session to talk (and sometimes sketch) through ideas that are causing difficulty for the student at that particular moment.

Peer Review Design Presentations: The peer review process is designed to encourage students to think outside of themselves and their own projects. Each group of students presents to another group, with the remaining classmates as the audience. Rotations are made so that each group presents once and is reviewed once. The process yields best results when this review takes place in the middle of the project, instead of as a final presentation.

Gallery Walks: Gallery Walks allow student groups to see what other groups are doing in a safe setting and supportive environment. Each group sets up a station of their project (i.e., a science fair format), with their physical artifacts, print-outs, and any sketches that help convey their ideas. This approach is unique in that the work needs to stand on its own. Group members do not present their work. This process, which can be made anonymous, is facilitated by the distribution of a list of specific questions for all groups. See an example gallery walk sheet to be completed by participants in appendix A.

The SCOPES-DF model design & build approach adheres to the principle that digital fabrication concepts and procedures are merely the means for students to "construct" meaning for themselves. It is important to note that these activities also provide students with an opportunity to explore topics of their personal interest in greater depth. For students to master digital fabrication concepts, teachers must acquire both the mastery of the Fab content matter and the pedagogical skills that will allow them to present the material to students at appropriate levels.

Catapulting Into Digital Fabrication" and "Fabber Sneakers Workshop" exemplify best practices when integrating digital fabrication into K–12 PBL environments:

https://www.scopesdf.org/scopesdf_lesson/catapulting-into-digital-fabrication

https://www.scopesdf.org/scopesdf_lesson/fabber-sneakers-workshop

Play # 3: New Tools and Approaches

FAB I CAN STATEMENTS

The word "assessment" is derived from the Latin verb assidere, which means to "sit beside." In K–12 formal education classrooms, formative assessments support student achievement by offering continual real-time feedback. Yet, the role of formative assessment within K–12 digital fabrication education remains poorly defined. The SCOPES-DF model conceptualizes formative assessment as a continuous and interactive process that measures individual achievement as well as the quality of the Fab learning experience.

The Fab I Can Statements are a formative assessment tool that measures achievement and the digital fabrication learning experience intended for K-12, and are the result of a collaborative effort between SCOPES-DF and the larger Fab Lab Network. Beginning with discussion at Fab 13 in 2017, the Fab I Can Statements have undergone three revisions. This collective effort strengthens the goal of articulating a unified set of Fab principles and practices for K-12 educators and digital fabrication learning communities. The Fab I Can Statements seamlessly connect classroom activities with benchmarked Fab teaching objectives. They also connect with state and national learning standards, as well as with broad outcomes for lifelong digital fabrication learning. By using Fab I Can Statements, students fabricate meaningful artifacts and participate in trans-disciplinary projects.

A.P.J. Abdul Kalam was one of India's best-known scientists and an aerospace engineer, before becoming the country's President. He stated that "If you fail, never give up because **F.A.I.L. means** First Attempt In Learning." This mnemonic device is commonly used in K-12 engineering classrooms. Through design thinking and iteration, students gain an appreciation that to FAIL is a natural part of the digital fabrication hands-on knowledge experience. The SCOPES-DF model also motivates students to engage in their own learning, plan and manage complex tasks, use feedback, and persist despite obstacles. Students are also encouraged to delve deeply into the subject and utilize multiple pathways of problem solving to justify their choices and proposed possible solutions. These students gain important Common Core/NGSS academic subject knowledge, as well as the development of a range of "noncognitive" skills and abilities such as SEL competencies, grit, and a growth mindset.

The Common Core Anchor Standards define the skills learners should demonstrate to be college and career ready. Whereas the Common Core/NGSS are scaffolded by grade level, the Fab I Can Statements are organized into six areas: Design, Computer Programming, Electronics, Modeling, Fabrication, and Safety. This reflects the numerous access points at which one can begin digital fabrication learning in or outside of school.

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DESIGN	
Design.1	I can be responsible for various activities throughout a design process within a group with instructor guidance.
Design.2	I can participate in design reviews with prepared presentation materials as well as give and receive feedback from peers.
Design.3	I can initiate design processes to generate multiple solutions to problems I have framed for multiple stakeholders.

Design is perhaps the most fundamental of all Fab Lab skills. It is often the most difficult to master while also being the most personal and, for many, the most rewarding. The design statements can be generally understood as progressing from novice to advanced skills; however, it should be noted that these statements differ in kind as well as degree.

Why These Design Statements?

DESIGN.1 Being able to work productively within a group is essential to design practice - at all levels. This statement also emphasizes the need for student ownership of parts of the process (e.g., doing research, making sketches, giving presentations). At this level it is assumed that teachers are guiding students through a predefined design process, e.g. the engineering design process.

DESIGN.2 Habitually documenting one's work within a design process is necessary for preparing and delivering successful presentations at key stages. The statement also highlights the importance of giving and receiving constructive oral and written peer feedback.

DESIGN.3 Problem framing and 'satisficing' - coming up with multiple 'good enough' solutions is at the core of good design practice. Recognizing that multiple solutions can exist. Yet trade-offs bring sophistication to the final result. Simultaneously, setting one's own schedule and sequencing for problem solving represent advanced thinking in design.

COMPUTER PROGRAMMING	
Programming.1	I understand the basic structure of a simple program and can modify values, variables, or other parameters to alter its output, function, or behavior.
Programming.2	I can create a program with more than one instruction.
Programming.3	I can create a program with multiple instructions and branching elements as well as reading / controlling inputs and outputs on a microcontroller board.

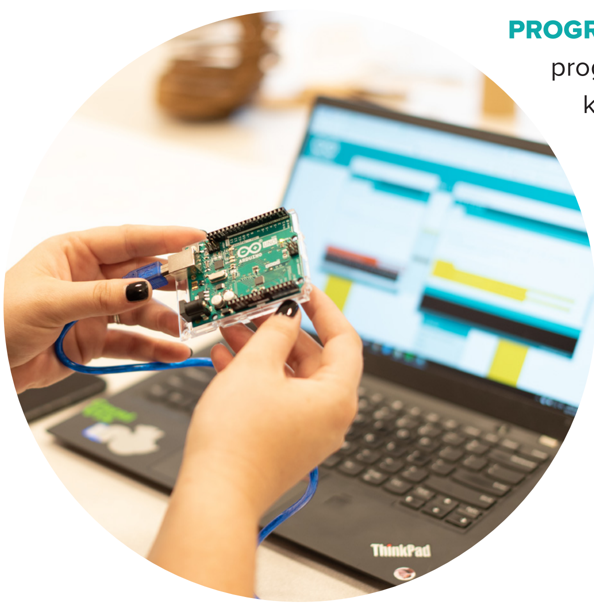
Computation, especially **computational thinking**, is important for success across academic subjects. One example is the use of computational tools with geometry to model two- and three-dimensional objects. Computation requires applying creative processes when developing **computational artifacts** and thinking creatively while using computer software and other technology to add logic and behaviour to objects.

Why These Computer Programming Statements?

PROGRAMMING.1 Being able to learn the fundamental concepts of programming that can be applied across a variety of digital fabrication projects. This includes modifying code in a visual programming environment (e.g., changing the values of variables to better understand how they impact the system). At this level it is assumed that teachers are guiding students through basic programming tasks.

PROGRAMMING.2 Using computational tools to read and understand basic code examples and recombining these examples to work together as an application or program that solves a previously stated problem.

PROGRAMMING.3 Understanding the fundamental principles of programming and the workflow/toolchain(s) used. Applying this knowledge to develop relatively complex applications and physical computing projects that include both inputs and outputs.



ELECTRONICS	
Electronics.1	I can follow instructions to build a simple electrical circuit using conductive material basic components and power.
Electronics.2	I can follow a schematic diagram and create a circuit including a microcontroller with electronic components.
Electronics.3	I can create my own schematic diagrams and use them to build electronic circuits including microcontrollers.

Electronics, especially in the area of **physical computing** teaches students how to communicate through computers and other components that are responsible for moving and controlling a mechanism or system. Electronics requires knowledge and use of sensors and microcontrollers to translate and process analog data using software as well as using software to control electro-mechanical devices such as motors, servos and other electronic devices.

Why These Electronics Statements?

ELECTRONICS.1 Learning the fundamental electrical concepts of electronics such as the use of wire, tape, and other conductive materials to power devices such as LEDs, switches, and sensors. This includes building a functioning circuit built on a paper surface instead of a printed circuit board or PCB. At this level it is assumed that teachers are guiding students through basic examples of electrical principles.

ELECTRONICS.2 Reading a schematic diagram, which is a graphical representation of an electronic circuit. This includes soldering circuits to power and control LEDs, resistors, capacitors, actuators, etc.

ELECTRONICS.3 Designing or modifying existing schematic diagrams is at the core for logic based electronic circuits that include microcontrollers, inputs and outputs with little teacher assistance and guidance.

MODELING	
Modeling.1	I can arrange and manipulate simple geometric elements, 2D shapes, and 3D solids using a variety of technologies.
Modeling.2	I can construct compound shapes and multi-part components ready for physical production using multiple representations.
Modeling.3	I can define complex systems with parametric relational modeling using generative, algorithmic, or function representation.

The modeling statements attempt to reflect the constantly changing nature of design software while promoting long-standing operations and terminology where possible. The statements are built around progressively advancing skills associated with progressively difficult-to-master softwares. Exceptions do exist, and it should be noted that modeling softwares are increasingly merging with programming environments as well as with fabrication tools. Furthermore, online browser-based software introduces additional skills such as account management, file sharing, and collaboration.

Why These Modeling Statements?

MODELING.1 Software types and brands largely constrain what kinds of geometry can be produced and how they can be manipulated. This statement refers to the use of introductory 2D, 3D, raster, and vector based tools. Also highlighted is the rising popularity of browser-based online software, particularly as intended for novice users.

MODELING.2 This statement emphasizes the context for which these skills are applied: modeling for physical production (e.g., this is in contrast to modeling for animation or rendering creation). *Compound* shapes refer to the use of boolean operations such as joining or subtracting geometry to produce shape complexity. In particular, this is necessary for multi-part components that require assembly after their fabrication (e.g., press fit assembly).

MODELING.3 This statement covers two topics. The first is what is being modeled: *complex systems*. This refers to electromechanical products typically with sensing and interactive capabilities. The second topic is how data are being represented. In parametric modeling, abstraction is introduced to ease information overload. However, defining the relationships introduces upfront overhead. Visual programming represents relational abstractions as connected graphs. Together these topics require that modeling skills become deep and broad.

FABRICATION	
Fabrication.1	I can follow instructor guided steps that link a software to a machine to produce a simple physical artifact.
Fabrication.2	I can develop workflows across four or more of the following: modeling software, programming environments, fabrication machines, electronic components, material choices, or assembly operations.
Fabrication.3	I can make my own applications, machines, or electronic components to solve new problems and to grow my Fab Lab's capacity.

The fabrication statements are written to reinforce a core tenet of digital fabrication competency - developing 'workflows'. That is, one does not learn to master a particular machine or software in isolation, but rather one must learn patterns of actions and thoughts that link together multiple machines, softwares, materials, and more to produce a physical artifact. The statements convey progressively increasing degrees of student autonomy as well as workflow depth for any given project.

Why These Fabrication Statements?

FABRICATION.1 A novice should be able to follow an instructor's steps for safely operating basic fabrication machines such as a 3D printer, laser cutter, or vinyl cutter to produce a single piece physical artifact.

FABRICATION.2 Moving beyond novice, a student should be able to plan and execute workflows through design software, introductory or block-based programming languages, machines of increasing complexity (e.g., CNC mills, routers), ready-made electronic components, and materials such as composites, metals, and polymers to produce a functional physical artifact.

FABRICATION.3 An advanced student should be able to make tools to solve problems that existing tools cannot. This can include custom software applications such as web interfaces or compilers, machines like multi-axis mills or robotic manipulators, and electronic components such as custom PCB's. Lastly, this statement addresses a core tenet of digital fabrication. Fab Labs should aim towards continual capacity building-either extending its own functionality by building machines that can build new machines or by building new Fab Labs altogether - self replication.

SAFETY	
Safety.1	I can safely conduct myself in a Fab Lab and observe operations under instructor guidance.
Safety.2	I can operate equipment in a Fab Lab following safety protocols.
Safety.3	I can supervise others in a Fab Lab and ensure safety protocols are being followed.

The safety statements are an essential guide for individuals to take precaution for their own safety in a lab environment. There is potential risk when working with lab equipment and materials, thus making safety a critical part of the experience. Each school or space introducing digital fabrication and other equipment and hazardous materials, is mandated to have safety guidelines and protocols. The statements of safety here are overarching and ensure safety protocols are included in student learning.

Why These Safety Standards?

SAFETY.1 Able to properly conduct myself and follow the guidance of someone responsible for supervising in a space for experimentation and manufacturing

SAFETY.2 Able to operate in a space for experimentation and manufacturing by safely following guidelines and rules of operation

SAFETY.3 An advanced state of understanding allowing care of self and others contingent with all safety rules and guidelines

Students learn via active participation and have opportunities to explore their own ideas through discourse, debate, and inquiry. Within this frame lies the presupposition that instructors assume a facilitator role while students are in charge of their learning. It is also assumed that the feedback during the design & build process serves as a scaffolding tool that supports and expedites learning. Finally, situated learning aspects involve students in cooperative activities as a part of which they are challenged to use their problem-solving, critical thinking, and kinesthetic abilities. The intent is to assess the students' Fab solution process separately from their academic performance. Classroom instructors can set short and long-term learning goals by:

- Asking yourselves what you expect your students to be able to do with Fab tools and resources after one semester, after one year, or after several years.
- Choosing specific Fab I Can Statements, or customize new ones, to establish learning targets for thematic units and lessons.
- Sharing with your students the Fab I Can Statements you are targeting for each day's lesson and showing them how those targets relate to the unit goals.
- Encouraging learners to set their own goals and providing the guidance and class time for self-assessment and reflection.
- Setting student learning objectives based on year-end proficiency targets as defined via the Fab I Can Statements. Educators can choose specific indicators from which to create SMART (Specific, Measurable Achievable, Relevant, Time-Bound) goals.

DIGITAL FABRICATION LESSONS

The SCOPES-DF website provides lessons that engage students in hands-on learning opportunities and other foundational elements of digital fabrication. The goal of these lessons is to provide students with an introduction to the principles of Fab learning and its place in K–12 classrooms. They offer an effective means to engage student thinking, promote discussion and collaboration, and encourage creativity, while prompting students to use a critical lens in applying Fab practices and techniques. In order to ease students into the digital fabrication, learning scaffolding in the form of guided questions and teacher notes are added. Each lesson is broken down into small steps, being careful to provide learners with one instruction at a time. Breaking down complex processes into simpler steps makes Fab learning a more attainable goal. Furthermore, each lesson in the SCOPES-DF collection reinforces CCSS/NGSS pedagogical shifts by incorporating the digital fabrication iterative design process. According to the NGSS Framework, "From a teaching and learning point of view, it is the iterative cycle of design that offers the greatest potential for applying science knowledge in the classroom and engaging in engineering practices" (NRC 2012, 201-2).

The following lessons offer beginner, intermediate and advanced level approaches to digital fabrication in K–12 STEM curriculum:

https://www.scopesdf.org/scopesdf_lesson/layers-of-the-earth-with-3d-printing

https://www.scopesdf.org/scopesdf_lesson/wind-turbine-stem-digital-fabrication-challenge

https://www.scopesdf.org/scopesdf_lesson/sand-casting-aluminum-parts

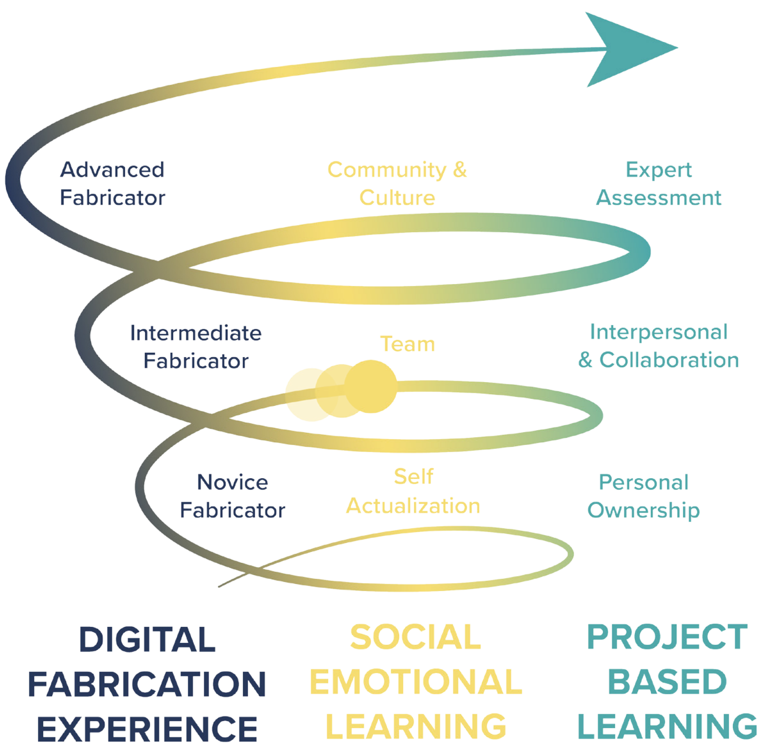
SPIRAL LEARNING PROGRESSION

In K-12 formal education, the National Research Council (NRC) for years argued for the use of learning progressions as a means to foster both deeper mastery of subject-matter content. Consideration of learning progression implementation is particularly significant in the context of the new Common Core State Standards (CCSS) and Next Generation Science Standards (NGSS) that attend specifically to the sequencing of topics and skills across grades to ensure attainment of college and career expectations by the end of high school. In a paper, *Learning Progression: Supporting Instruction and Formative Assessment,* prepared for the State Collaborative on Assessment and Student Standards (SCASS) of the Council of Chief State School Officers (CCSSO), UCLA Professor of Education Margaret Heritage writes:

> [An idea represented in the definition] of learning progressions is progression, that is, there is a sequence along which students can move incrementally from novice to more expert performance. Implicit in progression is the notion of continuity and coherence. Learning is not viewed as a series of discrete events, but rather as a trajectory of development that connects knowledge, concepts and skills within a domain.....A well-constructed learning progression presents a number of opportunities to teachers for instructional planning. It enables teachers to focus on important learning goals in the domain, centering their attention on what the student will learn rather that what the student will do (i.e., the learning activity), http://www.k12.wa.us/assessment/ClassroomAssessmentIntegration/pubdocs/FASTLearningProgressions.pdf

The teaching of digital fabrication research has not thus far established common terminology or definitions of a learning progression. The SCOPES-DF Spiral Learning Progression model is grounded on cognitive theory advanced by Jerome Bruner (1960), who wrote, “We begin with the hypothesis that any subject can be taught in some intellectually honest form to any child at any stage of development.” Key features of the SCOPES-DF spiral model are: (1) students revisit concepts of digital fabrication, social emotional learning (SEL), and project based learning (PBL) several times throughout their school career; (2) the complexity of each of the three areas increases with each revisit; and (3) new knowledge has a connection with earlier learning. The benefits of the SCOPES-DF spiral model are: (1) the digital fabrication skills are reinforced and solidified each time the student revisits the subject matter; (2) the spiral also allows a logical progression of SEL skills from self-actualization to intricate ideas of community and culture; and (3) PBL is motivated by a “driving question” that students explore as they continually revisit new concepts of personal ownership, collaboration, and expert assessment. The SCOPES-DF model enables students to develop the 21st Century competencies (both cognitive and socioemotional skills) needed for success in college and careers.

Figure 1



Spiral Learning Progression for K-12 STEM Digital Fabrication

ETHNOGRAPHY EVALUATION

Ethnography literally means a description of a people. In K-12 formal education there is a growing interest in the use of ethnographic techniques in program evaluations, also referred to as qualitative research. One of the main advantages associated with this type of evaluation is that it provides on-site real-time data to inform program implementation strategies. SCOPES-DF worked with the PAST Foundation, a leading authority in "monitoring program reliability though a culturally relevant, mixed methods approach," to develop an internal evaluation plan to monitor the 2018 Experiential Leadership Cohort implementation process. First, we developed evaluation guidelines that would ensure the areas of focus in our work, where we wanted to seed impact. This includes, but is not limited to, the role that teachers take in facilitating the learning (e.g., lecture, student guided), classroom environment and its implications for learning, student efficacy, engagement (between peers, between students and teachers), project adoption, and staff practice. Guided Questions for observations included:

- What were the learning objectives for this specific class period?
- What are the overall learning objectives for the current project/term?
- How did students respond to the material? The approach?
- What were the student demographics and profiles (i.e., types of learners)?
- How did that impact the learning and engagement?

After identifying equity, computational thinking and deeper learning as our targeted areas of inquiry, an observational tool was developed to ensure that multiple observers are focusing on similar issues in the digital fabrication integration process. Observable characteristics of teaching styles and classroom management techniques were identified. Elements of the observational tool includes:

Brainstorm: How did teachers facilitate student in:

- Tackling of a problem and envisioning potential solutions?
- Discussion of constraints?
- Discussion of appropriate tools?
- Discussion of appropriate materials?
- Discussion of appropriate processes?
- Teamwork and evidence of roles within each team?

Build

- Are multiple digital fabrication processes identified to create solution/product (e.g. 3D Scanning/Printing, CNC, Laser Cutting, etc)?
- Are multiple digital fabrication tools being used to execute product (e.g. 3D Scanner/Printer, CAD software, Laser Cutter, CNC, etc)?
- Is there peer-to-peer collaboration?
- Is there evidence of a design that will guide the build of a prototype (e.g., a plan, an outline, a sketch)?
- Are there Iterations?
- Are students encouraged to rethink approach or idea?
- Do students gather data or feedback at each step in the project?
- Are there questions or tests assumptions?
- Do students build support by sharing what they are doing with different people?
- Do students use feedback to make changes?

Modify

- Are the modifications driven by the testing results against answering the problem?
- Do students express an "ah-ha!" moment or breakthrough in understanding concepts?
- Are students learning from one another's mistakes or proposed solutions (i.e. peer-to peer- learning)?
- Is there teamwork and evidence of roles within each team?

Presentation

- Do presentations address problems being solved and how solutions were applied versus a simple description of the product?
- Do the solutions drive new questions?
- Is there teamwork and evidence of roles within each team in presenting the process for solving the problem and creating the solution?

Additionally, focus group participants were asked the following questions:

- How comfortable are you with using digital fabrication in your subject area?
- What do you see as the most important benefits of digital fabrication in STEM education?
- What has been the biggest challenge with developing and implementing the approaches recommended through the SCOPES-DF project in your classroom?
- What kind of feedback have you had from your students about these approaches, if any?
- How would you like to include your students/student voices in the project?
- How would you describe the differences in your teaching due to your work with SCOPES-DF?
- How would you describe your experience in collaborating with other teachers as part of the SCOPES-DF project, both in your school and with others involved through the SCOPES-DF project?

One of the most appreciated aspects of ethnographic research is its depth. Because the observers are on-site, the ethnographer sees and reports what teachers are actually doing in the classroom as well as what they say they are doing. Furthermore, knowledge of what happens in the field can provide vital information to challenge our assumptions. The PAST Foundation's external evaluation allows the SCOPES-DF team to identify areas and ways program implementation fulfilled our expectations and the lessons learned when they did not.

One of the main disadvantages of ethnographic research is that it takes longer than traditional pre-/post-evaluation research. Not only does it take time to do the fieldwork, but it also takes time and effort to analyze the data and record results. Our goal is to continue using the qualitative data collected to inform our growing knowledge of the practical, theoretical, and pedagogical aspects of K-12 digital fabrication classroom integration.

Summary

In today's knowledge-based economy, the ability of K-12 schools to acquire, develop, and strategically leverage knowledge has become a crucial factor for global competitiveness. Models of educator development that are embedded and curated offers a powerful catalyst for empowering educators to modify or improve their digital fabrication learning and STEM teaching practices. SCOPES-DF's adoption of a Community of Practice links educators and makers to support student learning in digital fabrication. Teachers, as community members benefit directly from their participation in the Fab Lab Network. This shared context increases networking between traditional and informal educators, and supports real time learning across professional fields and culture. This harnesses the kind of intersectionality that cultivates new thinking. Collective knowledge is then remixed and modified, and thereby transformed into new learning opportunities.

The SCOPES-DF model offers a perspective on digital fabrication and STEM knowledge sharing that is compatible with the *constructionism* epistemology advanced by Seymour Papert. However, identified successes in this *Playbook* are mainly based on short-term qualitative, case-study oriented research. Thus, further implementation is needed to explore whether these findings can be strategically scaled.

To broaden the perspectives of K-12 digital fabrication, additional work is required to uncover the impact of the new tools and approaches from the SCOPES-DF project. Further adoption in different schools and various classroom settings (i.e., underserved populations, single gender classrooms) will allow us to study effects more broadly. Additionally, a longitudinal study could address the question of measuring the impact on student achievement.

We hope to continue this path of research through collaboration with educators who are willing to test these tools and approaches in their daily practices. Please join us in the pursuit of using digital fabrication to benefit student learning.

APPENDIX A

Design Review: Gallery Walk

Design reviews are intended to solicit constructive feedback from both peers and instructors. Be prepared to give feedback to your peers. Include the following:

Remember to be constructive: acknowledge the positive and give specific feedback with specific solutions.	
1. Describe. What things do you see? Describe the elements in the work (ex. materials, techniques). Explain what you see.	
2. Analyze. How are science, math and digital fabrication elements used in the project? Find examples that make use of these subjects.	
3. Interpret. How does the project convey the overall theme of the workshop?	
4. Decide/Evaluate. Do you like this project? Why or why not? What is the best thing about this project? What can be improved?	

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Acknowledgments

Writing a *Playbook* for our growing community of educators, fabricators, and makers has been humbling and exhilarating. As quality education and opportunities for youth worldwide become increasingly complex to deliver, our goal is to do our part and use digital fabrication as a platform for deeper learning and engagement for all.

In providing support to those of you who are on the front line and directly serving our youth and teachers all around the world - we thank you and hope this document is a tool for you.

It takes a team of brilliant, collaborative, and energetic people to answer a call that responds to requests for additional resources. The *Playbook* would not be possible without the hard work of those whose life's work is in STEM, education, and community development. This reflects long hours of research, testing, and revisions through the leadership of the SCOPES-DF team: Simone Billings, Dr. Nettrice Gaskins, Melvin LaPrade, and Dr. Dan Smithwick. Also, we are grateful for the Fab Lab Network, Fab Foundation Board, and the entire Fab Foundation staff: Fiore Basile, Luciano Betoldi, Alethea Campbell, David Cavallo, Norella Coronell, Pamela King, Sherry Lassiter, Jean-Michel Molenaar, Aidan Mullaney, Rebecca Ottinger, Jean-Luc Pierite, Sonya Pryor-Jones, and Brian Purvis.

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