Assessing Wisconsin's K-12 Fab Labs
Employing Process Mapping to Identify Best Practices

Fab Lab and Assessment Overview:

The Fab Foundation (http://fabfoundation.org/) describes digital fabrication laboratories (fab labs) as a collection of digital technologies in an open, collaborative setting that serve to advance learning and innovation. Typical equipment accessible within fab labs include: a laser cutter that makes both 2D and 3D items; a vinyl cutter that cuts a range of materials - including copper to serve as the basis for building flexible circuits; a CNC milling machine that makes circuit boards and precision parts; a large format router for building 2D and 3D structures; a 3D printer to build representative prototype designs; and a collection of electronic components to build low-cost, high-speed microcontrollers.

According to the Fab Foundation, while "originally designed for communities as prototyping platforms for local entrepreneurship, fab labs are increasingly being adopted by schools as platforms for project-based, hands-on STEM education"…"In educational settings, rather than relying on a fixed curriculum, learning happens in an authentic, engaging, personal context, one in which students go through a cycle of imagination, design, prototyping, reflection, and iteration as they find solutions to challenges or bring their ideas to life."

In association with the Fab Foundation and UW System, UW-Stout has become a regional center for the fab lab network, supporting the introduction of fab labs throughout Wisconsin and facilitating their entry into the Fab Foundation's global network. Recognizing the role UW-Stout plays, the Wisconsin Economic Development Corporation collaborated with the UW-Stout Discovery Center to build a project team with a focus on gaining a better understanding of Wisconsin's fab labs and potential opportunities to build a value-add statewide network.

The project team utilized Processing Mapping, a quality management tool that produces a detailed flow diagram of a process, to identify the activities and outcomes of Wisconsin's digital fabrication laboratories (fab labs) operating in K-12 education settings during the 2015-16 school year. Included with the Process Maps was a list of equipment and software deployed in these fab labs. For each fab lab assessed, the project team identified local fab lab team members to assist in the creation of their local fab lab's process map.

Fab labs participating in this assessment were considered as operating within one of three categories – with corresponding characteristics:

1. Fully operational (>6 months) – Established team of educators from the school district engaged in developing curricula, lesson plans, activities and assessing outcomes from the fab lab within the classroom; and active participation from and partnership with community members and local employers.
2. Start-up (<6 months) – Emerging team of educators and community members from the school district involved in fab lab start-up activities; purchased and installed digital fabrication equipment and have started to make changes to curricula.
3. Exploratory – Identifying a team to develop a fab lab; planning for securing equipment or centralizing equipment for use in a fab lab.

Assessment Outcomes:

Assessments of the various Fab Lab models occurred in a standardized process utilizing two basic tools or methods.

First, a *boundary worksheet* identifying key process components (Table 1.) was drafted to establish boundaries that could be used in better scoping and laying out the fab lab processes. Fab lab representatives as well as process facilitators and Project team personnel were included in the discussion and documentation of the fab lab boundary worksheet and subsequent processes.

Table 1. Boundary Worksheet Components.

Item	Description
Input(s)	Product or service coming into the fab lab process that is acted upon.
Supplier(s)	Individual or group who produces the product or service used as the fab lab process input.
Supplier Specifications	Translation of the customer requirements into the supplier specifications.
Output(s)	Product or service that is produced as part of the Fab Lab process and is passed on to the next person in line.
Customer(s)	Next person or group in the work process who receives outputs and acts upon them.
Customer Requirements	What the customer wants, needs or expects from the output.

A boundary worksheet from an assessed lab (Table 2.) can be found on the following page.

Table 2. Boundary Worksheet from Project-Assessed Lab.

Input(s)	Supplier(s)	Supplier Specifications
A product or service coming into your process that is acted upon.	*An individual or group who produces the product or service you use as your input.*	*Your translation of the customer requirements into the supplier specifications.*
1. Raw Materials (polymers, metals, composites)	1. Local vendors, industry donations	1. Must be local if possible, just-in-time, flexibility & empowerment in purchasing (i.e. send student, streamlined P.O. process)
2. Equipment	2. Vendors (local, national), industry donations	2. Affordable quality vs. quantity, right-size for students, functional for students (i.e. software), educationally appropriate
3. Students	3. Parents, elementary/middle schools	3. Attendance, willingness to learn, open to opportunities available, parents' knowledge & awareness of offerings, flexibility
4. Prior Student Knowledge	4. Parents, elementary/middle schools, current students, student life experience, community	4. Student mentorship to pass on knowledge/passion, teamwork, pre-requisite courses, work ethic, willingness, method of thinking (design, problem-solving, critical thinking, practical)
5. Staff Members	5. Universities	5. Broad-based thinking, mentorship & relationship building, passionate about student success and content, knowledgeable of current practices & application of content, continuous learner
6. External Mentors	6. Local business & industry, community volunteers (parents, retirees, teachers-summer camps/outreach programs)	6. Willing & available to put in time, work well with & relate to students
7. Problem or Opportunity (need)	7. Instructor, student on occasion, industry	7. Prior experience, age appropriate within student skillset
8. Career & Skill Needs for Future, Industry Trends (manufacturing needs)	8. Business & industry	8. Skills gap identification for future
9. Community Support (Time, Philosophy, Vision, Core Values, Encourage Intellectual curiosity, trust)	9. Parents, industry, teachers, administrators	9. Passion, knowledge, belief in program
10. Educator Knowledge	10. Educator, university, tech colleges, business & industry	10. Continuous learning, teamwork & collaboration, ongoing professional development

Next, a *process map* (Figure 1.) was created to illustrate the relationships and processes linking the items revealed in the boundary worksheet. The team found that each fab lab assessed utilized a standard engineering design (Figure 2.) or scientific process in the development of ideas or problem solving activity.

<u>Figure 1</u>. Process Map from Project-Assessed Fab Lab.

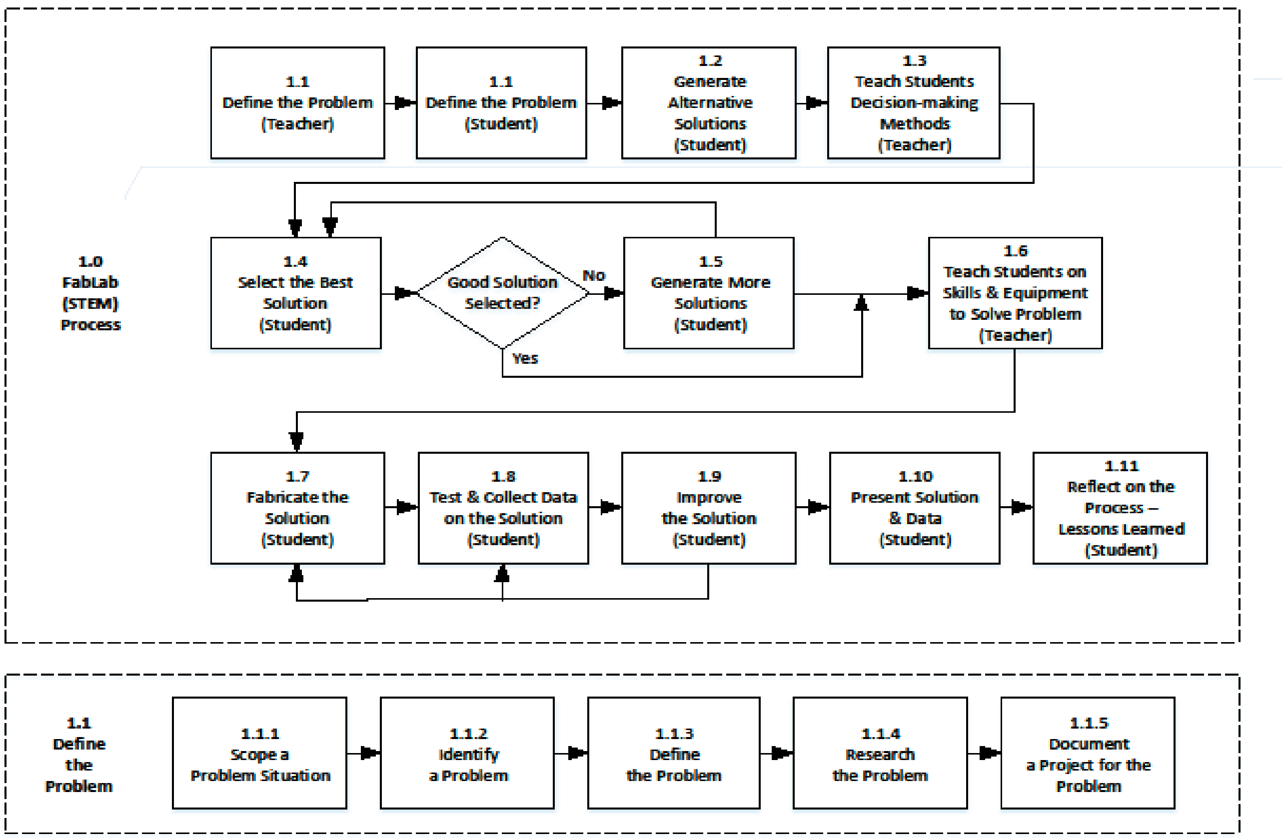
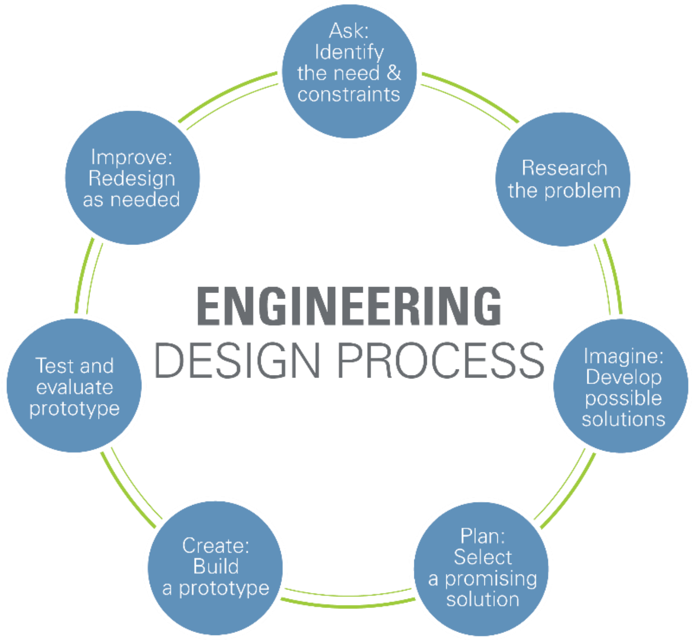


Figure 2. Engineering Design Process.



Retrieved April 25, 2016, from https://www.teachengineering.org/engrdesignprocess.php.

While the fab labs in the study had this basic similarity, there was variance in maturity, terminology, community involvement, and overall process flow. The fab labs visited were at different levels of maturity, from just starting in the current school year to existing 1-2 years or more. Each fab lab used slightly different terminology and had variation in their processes overall. For example, a school may call their facility a fab lab, STEM (Science, Technology, Engineering, Math) lab, or STEAM (Science, Technology, Engineering, Art, Math) lab. Additionally, some fab lab staff had attended MIT's "How to Make Almost Anything" fab guru training while other fab labs had not attended training but may have been involved with regional fab lab related seminars or training. Another difference was the degree of involvement from the local community in the maintenance of and services provided by the fab lab.

Focus Groups were also convened with K-12 Districts that are in the Start-up or Exploratory phases of development. The outcomes of these Focus Group discussions are summarized below.

Focus Group Comments Summary:

Origins and Current State:

- Each participant summarized the current state of their digital fabrication/STEM efforts;
- Sources of funding included private grants to purchase fab lab equipment, now trying to navigate through creating a curriculum and measuring the outcomes;
- Attracted to a design process established for the K-12 and to use as a community resource;
- Interest in accessing elementary level students with makerspace, robotics team, etc.;

- Interest in integrating Lego robotics, makerspace workshops for faculty in summer;
- Interest in two types of labs: tech and traditional (“clean” and “dirty” areas);
    - 3D printers are common starting point due to visual appeal;
- Local business connections essential;
- Large scale school expansion in one district allowing for more strategic engagement in fab lab, and to work more closely with local technical college;
- Kids eventually pushed their teacher into utilizing the schools' lab for their class; and
- Problem with faculty not necessarily working together, but the students are engaged.

Challenges and Opportunities:

- Groups were apprehensive about what to label the program, pros and cons for “fab lab” brand;
- Worried about mixing curriculums together and filling Tech Ed vacancy;
- Location within school presents challenges (computer lab? wood and metal shops?)
- Opportunity to increase the exposure so more students utilize the engineering and tech side, with window highlighting 3D printing capability;
- Looking at ways to integrate fab lab into Project Lead the Way;
- Trying to make it more of an open lab, cross disciplinary, bring in more areas to utilize the lab;
- Open lab opportunities will assist in bringing in cross disciplinary development and engagement;
- Difficulties getting quality teachers for advanced positons like physics and chemistry; and
- Limited time and resources for teachers;

Metrics and Path Forward:

- “if students are in the lab, then there’s a success”
- One option is adopting MIT model;
- Seek training during summers to hone skills; and
- Need for director, coordinator or facilitator at school level;

Results

The results of the fab lab assessments were systematically arranged into four categories from existing research: *student*, *faculty*, *community*, and *industry* outcomes. The categories were chosen as they met similar criteria of the WEDC initiative. In order for a sustainable economic impact to occur in the Wisconsin industrial system, supportive community and educational systems have to distinguish unique competitive advantages for ensuring the sustainability of Wisconsin's economic development. Student and faculty outcomes comprise the essential components needed in order to impact the community and industrial economical needs.

Student

Student results was the only category that contained four sub-categories – learning outcomes, academic achievement, technology proficiency, and developmental outcomes – and illustrated similar criteria needed in order to conduct quantitative assessments of fab lab's outcomes (Lei, 2009).

Fab lab programs employed an engineering method that instructed students through projects, which was the main focus of each Project curriculum. Each engineering method was commonly associated with a unique name, and slightly different foundational prospective on how the engineering method should be administered. The distinction between and among methods is partially detected within the school's learning foundation. One assessed school utilizes the engineering process with a foundation exclusively in science, technology, engineering, and math (STEM) to solve problems. Others incorporate an art/design component into the STEM foundation, or STEAM.

The engineering method is further customized to meet the expectations and demands of alternative programs. An alternative charter program assessed focused its students on an engineering design process that has customized its foundation to represent science, tinkering, engineering, aesthetics, and math for a four-year long experience with an interdisciplinary fab lab curriculum component. One assessed lab provides access to students from neighboring school districts with the opportunity to experience the STEM design process through classroom or extracurricular experiences.

Table 3. Learning Outcomes

Engineering Method
Design Process
Engineering Design Process
Engineering Method
Engineering Process
Learning Foundation
Science, Technology, Engineering, Art/Design, Math
Science, Tinkering, Engineering, Aesthetics, Math
Science, Technology, Engineering, Math
Accountability
Adaptability
Collaboration
Critical Thinking
Efficient
Knowledge, Skills, Ability Application
Life Long Learner

Student learning outcomes (Table 3.) were then categorized across multiple learning foundations and engineering methods applied to student's curriculum. All provided the opportunity for students to develop and exercise their accountability, adaptability, collaboration, critical thinking skills, efficiency, KSA applicability, and establish themselves as life-long learners. These areas are generally combined and elaborated on in their own unique way depending on what the school's curriculum utilizes.

Academic Achievement

A variety of methods are utilized among the Project schools on how they define their academics. Distinguishing features that customize the schools are credit type, grade measurement, student projects, sponsorships, co-ops, and internships (Table 4.). Subsequently, these very distinct features unanimously consist of encouraging and promoting students to go on to continue their education or pursue STEAM careers.

Credit type is generally labeled apprehensively because of the fab lab's interdisciplinary components. Some label fab lab classes as elective or general credits that provide no distinction of what material is learned in the classes. Others provide specific credit accommodation to match the appropriate classroom learned material. The labeled credits are subjectively decided upon based on the main learning goal of the project or class. Credit is not always offered, but may be an opportunity for classes or individual students may explore as an extracurricular option.

No matter what grading measurement is utilized, a recurring theme is the encouragement to fail in the process of learning while completing projects. This perpetuates the method for continuous student exploration and growth as students use their own knowledge, skills and abilities to solve their failure, and view it as an opportunity to improve upon themselves. The most prevalent fab lab grading measurements with nearly distinct pass or fail measurements. This concept allows students to put in the amount of energy and quality they feel the need to into the project. One approach is to allow students to disperse the amount of energy and quality to gain an A, B, or C (5,4,3 points) or redo because it is unsatisfactory (D or F, 2 or 1 points). The key component in this grading system is that the student only fails if they choose to fail.

Table 4. Academic Achievement

Credit Type
Elective
General
Specific
Not Available
Grade Measurement
5.0 scale (5-3 Pass 2,1 Redo/Fail)
Pass/redo
Standard GPA
Not Available
Student Projects
Preplanned stages
Rubrics for projects
Self-explorative during stages
Specific Courses
Sponsorship
Business Advisory Board
Organizations
Organizations/Advisory Board
Nothing
Co-op's
Local organizations
Variety
Nothing
Not Available
Internships
Lab coordinator sets up
Local organizations
Variety
Not Available
Continuing Education
STEAM Careers

Student projects ranged from specific planned stages throughout the coursework to planned stages with a varying degrees of autonomy. In some cases, course projects were specifically designed to meet the criteria designated from the course instructor, while in other cases projects were guided by what student's wanted to achieve. One Project district encourages self-explorative stages which are designed to utilize every aspect of their fab lab with any amount of creativity the student applies. There are the fewest restrictions with these projects as it strongly encourages multidisciplinary studies and a large degree of creative freedom. Fab lab sponsorship plays an essential role for not only the financial sustainability of the program, but for providing students with the opportunity to apply their skillset in an industrial setting through co-op and internship opportunities. Industry advisory boards may not necessarily have an industrial need for fab labs, but often support the sustainable impact provided by them. A successful model uncovered in the assessment provides a combination of both organizational and industry advisory board sponsorship, which in return provides a variety of local and national co-op and internship opportunities.

Technology Proficiency

Students' proficiency with software and equipment is completely circumstantial to availability and program curriculum. Mastery of technology is generally tracked with the grade measurement and student projects completed. It is quite common that technology is learned in a collaborative manner whether students naturally help others (peer-to-peer learning) or are required to collaborate in group efforts.

Developmental Outcomes

The ending point (Table 5.) of any version of the engineering method is the dissemination of results, which assist in perpetuating the research in the field for further discoveries. The K-12 programs provided strong support for the dissemination of results. Schools with local area sponsors regularly present their projects as a means of professional development and advancement in fab lab related fields. There is also a collective effort among the schools for conducting as many class presentations as possible while also utilizing any available opportunity for conference dissemination.

Beyond the availability of disseminating the results, the Project schools unanimously support numerous sustainable social practices with higher education and industrial fields. A highly sought after social outcome for fab labs is increasing female enrollment and altering female stereotypes. The remaining unanimous developmental outcomes are the following: career exploration; creativity; healthy competitive nature; helping other students; life skills; positive school attitude; risk assessment; positive self-esteem; teamwork; and trust. Each of these outcomes assists in advancing students' interest in STEAM and/or STEAM careers.

Table 5. Developmental Outcomes

Class Dissemination
Yes
No
Sponsor Dissemination
Yes
No
Conference Dissemination
Yes
No
Break Woman Stereotypes
Career Exploration
Creativity
Healthy Competitive Nature
Help other students
Life Skills
Positive School Attitude
Risk Assessment
Self-esteem
Teamwork
Trust

Faculty

Each of the assessed schools' operating faculty had some form of instructional training or certification to bolster fab lab knowledge, skills and abilities, and to improve outcomes (Table 6.). One district's faculty has undergone traditional MIT Fab Lab training through classes available remotely through the University. Lessons learned are also shared with not only the students, but other faculty members in order to increase faculty experience and increase availability for students to utilize the fab lab.

Other schools endorse a STEM based operation of their lab. The faculty collaboratively work together with K-12 schools, colleges and industrial businesses to continuously improve upon STEM-based learning. This is commonly accomplished through workshops, conferences and training programs. Numerous local, national and international resources are accessed to expand upon and leverage expertise with robotics, milling and WTEA training resources.

Table 6. Faculty Outcomes

Professional development
STEM Based
Robotics/Mill/WTEA Training
MIT Training
Local Training
Interdisciplinary Studies
Yes
No
Progressive Equipment
New
Donated
Educational Aides
Increase Female Enrollment
Progressive/growing Curriculum
STEAM/STEM Implementation

Community

Public schools play a significant role in their communities (Table 7.) as they educate citizens who in return influence how the school system operates. These fab labs offer open lab times and workshops for citizens to learn and utilize the fab lab. Each assessed lab encourages entrepreneurship opportunities during their community times to fab lab participants.

Table 7. Community Outcomes

Available Resources
Community Times
Inventor/corp. support
Local Assistance Only
Entrepreneur Opportunity
No
Yes
Family Events
Family times
None Available
Parent showcase night
Intergenerational Collaboration
Mentorship/Training
None Available
Workshops
Community Availability
Middle School Recruitment
Technology Awareness

A best practice is to offer intergenerational collaboration between students and citizens during community times, where students or citizens may assist each other with fab lab training or projects. One assessed lab has family times designated towards fab lab collaborations between students and their families. This includes times when families have the availability to come into a family structured setting to work together as a fab lab family team. Another hosts events where students showcase presentations for parents to view.

A community outcome prevalent in each Project school district is spreading technology awareness to the community. This is an essential component to communities, as technological advancements and availabilities play an important role in establishing more sustainably focused industrial communities.

Industry

One of the main reasons for fab labs in Wisconsin schools is to provide an increased pool of talented industrial workers. The assessed fab labs provided multiple outcomes (Table 8.) in terms of benefits from fab lab and industry partnership for Wisconsin industry, such as industrial sponsorship between fab labs and local industries. Each fab lab utilizes their lab as a means to develop a trained and talented workforce to meet local industry's

increased technology requirements. Because of the strong partnership between local industries and fab labs, students generally have the opportunity for employment within these organizations. One of the sponsoring local organizations utilizes their donation to the fab lab to recruit leading engineers to the area, and in return these engineers' children have an advanced education through the organization's sponsorship of their school's fab lab.

Schools with stronger industrial sponsorship or business advisory boards also provide a form of marketing for the local organizations. This is philanthropic approach establishes a community culture in the school. Ultimately each assessed fab lab is designed to benefit some aspect of the local communities' culture. This is demonstrated through unanimous industrial outcomes of having the ability to locally solve problems, while competitively expanding industrial interest into more widely accepted industrial standards and expectations which fab labs contribute towards.

Table 8. Industry Outcomes

Training Prototype
Yes
No
Employment Opportunities
Yes
No
Employee Recruitment
Yes
No
Marketing
Yes
No
Philanthropy
Yes
No
Community Culture
Locally Solve Problems
Expand Industry Interest

Recommendations

1. Integrate problem formulation and problem solving processes, engineering design and/or design thinking into K-12 fab labs to drive more impactful outcomes;
2. Develop local business advisory boards and secure local organizational sponsorships which are necessary for both a sustainable financial fab lab and to contribute to competitive job growth in Wisconsin. Business advisory boards are also beneficial with networking opportunities and community support even if they don't provide direct financial support;
3. Establish a regional network for K-12 fab labs to provide equipment training and optimization, curriculum integration and to introduce leading-edge technologies as they are added to the fab lab network; and
4. Implement a rigorous longitudinal study of students' fab lab experiences and outcomes, providing the analytics to determine whether Wisconsin fab labs actually produce competitively educated students that expand Wisconsin STEM-based educational outcomes and industrial standards. Ideally, a mechanism could be developed to:
   a. Track whether graduating students from fab labs are going into higher education and/or related work fields, along with identifying where they're geographically locating (distinguish whether the fab lab had an economic impact for Wisconsin);
   b. Track the frequency of student's disseminating their projects, along with what type of viewing audience the project is presented to. Dissemination is an important student outcome, as students develop the appropriate social skills needed to expand fab lab research (Gershenfeld, 2012). This will also further develop their STEM interest as students expand their presentation skills into the real world with more sponsor, conference or business advisory board presentations;
   c. Have students self-reflect upon their ambitions towards their fab lab experiences and why/why not they have interest in continuing into STEM or STEAM careers, as well as how they would improve upon in their fab lab experience in the beginning and end of each academic semester since reflective practices are an essential component of interactive learning environments (Stevens, Gerber & Hendra, 2010);
   d. Apply the STEAM Activation Learning Survey to random student populations as a recruitment and assessment tool for students who would not normally be introduced to STEM disciplines. The survey has been psychometrically tested to be a reliable tool used to access students' STEM fascination, values, competency beliefs and the innovation stance. The survey should also be applied to the students who venture into the schools' fab lab programs and to track their progression; and
   e. Apply the Engagement Survey with students who achieve the glass ceiling in the STEM Activation Learning Survey or are already immersed within the fab lab curriculum. This survey is designed to measure the engagement in the fab lab activities students' conduct. This should generally be administered three times throughout the academic year, with students participating after their first project, and after their last two final or most significant projects of each semester.