Digital Promise Global

Student Growth through Design-Centered Learning
Report from the Learning Studios Pilot

I. Introduction

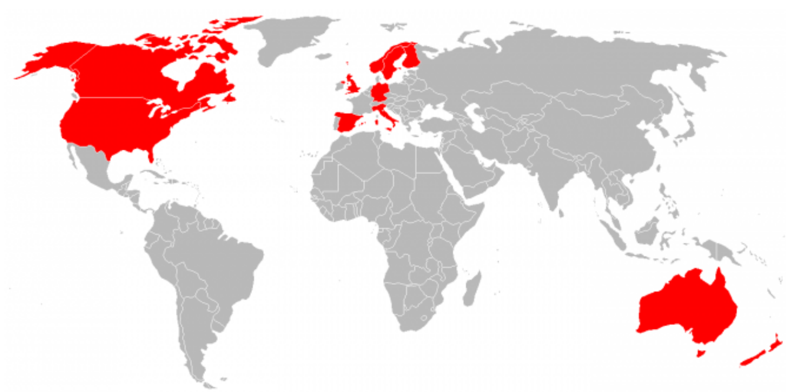
Recent years have seen the emergence of design-thinking and maker learning initiatives across formal and informal learning environments. A variety of offerings, from museum and afterschool programs, to STEM challenges and entrepreneurship courses, create opportunities for young people to develop skills relevant to today's workplace. Design-based learning emphasizes the importance of creative problem-solving, taking perspective and empathizing, identifying problems worth solving, and iterating on solutions. Yet despite high relevance to 21st century workforce demands, opportunities for young people to engage long-term in design-based experiences remain limited.

With the support of HP and Microsoft, Digital Promise Global's Learning Studios program brought enhanced design-based learning opportunities to teachers and students in 60 schools in the US and abroad. The Learning Studios program provided advanced technology, design-based learning resources, and an online teacher community to participating sites, and the first implementation spanned the 2016-17 school year. To capture and share outcomes and insights from the Learning Studio implementation project with the larger community, an exploratory research component was included as well.

This report presents the key outcomes of that research, and is organized in four main sections. To set the research in context, details on project resources and implementation are described in the remainder of this section. In the second section, we explain how the research was organized and the ways that data were gathered and analyzed. Section three presents key thematic findings across survey, interview and focus group data. In the fourth and final section of the report we reflect on opportunities for additional research and share recommendations for future implementations of Learning Studios and other design-based education programs.

1.1 About Learning Studios

Learning Studios is a design-based learning initiative directed by Digital Promise Global as part of HP and Microsoft's Reinvent the Classroom initiative. The goal of the project is to create new opportunities for student-centered, experiential learning by equipping schools with advanced technologies for creation and collaboration. A total of sixty school sites spanning 11 countries participated in the program between May 2016 and May 2017, as illustrated in Figure 1. Each site received a technology and resources package that included a 3D printer, a desktop computer with integrated 3D scanner and interactive touchmat, and notebook computers, as well as additional technologies and materials. A full list of the Learning Studio package appears in Figure 2.



Country (# sites)

- Australia (4)
- Canada (5)
- Finland (1)
- Germany (1)
- Italy (1)
- New Zealand (1)
- Norway (1)
- Spain (1)
- Sweden (1)
- United Kingdom (3)
- United States (41)

Figure 1: Learning Studios Implementation Countries and Sites

- Sprout by HP
- 10 HP x360 310 G2 Convertible Notebooks
- Dremel Idea Builder 3D printer
- HP Printer with Pagewide Technology
- Large format presentation display
- Notebook storage unit.
- Supplemental kit:
    - 4 Makey Makey invention kits (donated by Joylabz)
    - 1 class pack of Model Magic (donated by Crayola)
    - 2 additional spools of PLA filament (donated by Dremel)
    - 1 Cardboard Construction Kit (tape measure, utility shears, fasteners, etc)
    - 1 Take-It-Apart Kit (pliers, screwdrivers, etc)

Figure 2: Learning Studios Technology and Equipment

In addition to providing technology resources to participating schools, Digital Promise Global offered a range of instructional and professional development supports to teachers. An online Teacher's Guide, together with a collection of ten project guides for students, were available for educators to draw upon at their discretion. Four of the projects were recommended in a sequence between September and November 2016 for teachers to prepare students for the culminating Global Goals, Local Solutions project. From January to May 2017, an additional three project guides were published leading up to the final Play to Learn project. Sample project guides from both phases are included in Appendix A.

Teachers also had access to an online community in which they could connect with other Learning Studio educators to share and collaborate on new ideas, discover resources and project ideas, share classroom stories, and get support and tips from Digital Promise Global instructional coaches on ways to use related technology tools in their classrooms. Teachers also had access to a webinar series conducted by program staff, and one-day of professional development on the technology, provided in person by Educational Collaborators.

1.2 Implementation Models

At each site, a "Lead Educator" served as the primary point of contact with Digital Promise Global. Schools were encouraged to invite additional teachers to use the equipment, projects, and online supports as well. While a single teacher engaged with the program at most sites, as many as seven teachers participated at some sites. In terms of timeframe, the original Learning Studio implementation spanned May through December 2016. In response to the project team's conversations with participating teachers during the fall of 2016, the project was extended through the end of the U.S. school year. The original set of project guides remained available to teachers. Digital Promise Global added a second culminating challenge and related supplemental projects focused on game design and titled "Play to Learn". From January to May 2017, at each teacher's discretion, students continued to work in the Learning Studio on the projects provided by the program, or on other projects, using the equipment and resources provided, and took part in the newly added Play to Learn Challenge.

For several reasons, implementation of the Learning Studio program was markedly different across sites. Sites were selected from a range of locations within the United States and abroad to create a global community of participants, and to create opportunities for teachers and students to interact with peers around the world. In addition, sites were selected across grade levels, from elementary through high school. Instructional context was another distinguishing characteristic. Sites were diverse in this respect, ranging from afterschool programs, to use with existing curricula such as Project Lead the Way, to weekly maker sessions. Moreover, teachers brought diverse backgrounds in design-based teaching and learning to their participation as facilitators of student engagement. Some teachers had extensive experience with design-based teaching, and were comfortable with students taking the lead on their design projects and with the technology. In contrast, others were relatively new to the technology as well as to instructional approaches in which the teacher serves as facilitator.

An additional factor contributing to the variety of implementation models is that the program intentionally gave teachers wide latitude to choose which projects to carry out with their students. Learning Studios imposed minimal requirements on participating teachers and students, asking only that they complete the Global Goals, Local Solutions Challenge project between November and December 2016. Conceived as a culminating project in which students would draw upon the knowledge and skills they had built through preceding projects, the Global Goals, Local Solutions Challenge prompted students to collaboratively design and produce a local solution to a United Nations Sustainable Development Goal.[1] Finally, the extent to which sites took advantage of the 2017 extension of the program varied, and in some cases a new cohort of students came on board in January of 2017.

Taken together, the contextual differences and the variations in implementation across sites resulted in substantial differences across students' experiences with the Learning Studios. This diversity was a deliberate characteristic of the Learning Studio program, and we intentionally gave precedence to implementation values over research design considerations, which would have limited differences across site characteristics and required similar project work for all students. In the following section describing the research design, we elaborate further on the implications of the Learning Studio implementation diversity for interpretation of results.

2. Research Design and Data Collection

Research on the Learning Studio initiative was carried out by Designs for Learning in collaboration with Digital Promise Global, representing a hybrid third-party approach. Designs for Learning maintained an independent role in data collection and analysis, while also working cooperatively with the Digital Promise Global team to inform the impact goals for the project and to interpret results.

The purpose of the Learning Studios research was to understand how teachers and students made use of the advanced technologies provided by the project, and to document the areas of growth experienced by students and teachers—from technology skills to design-based thinking and related competencies. We also sought to understand the effects of implementation context on technology use and learning. Finally, we wanted to capture insights related to challenges and best practices that could inform the broader field.

[1] http://www.un.org/sustainabledevelopment/sustainable-development-goals/

As noted in the previous section, the grassroots nature of the Learning Studio program yielded substantial variation across sites in terms of context and implementation strategies. We expected that students and teachers would benefit from participation in the program; however, we also knew that benefits were likely to vary with contextual factors such as grade level, curriculum constraints, and student exposure.

Another factor informing our choice of research design was the relative lack of prior studies on outcomes associated with design-based learning and maker learning initiatives. Because our research would contribute to a nascent body of knowledge about the ways that design-based learning experiences benefit students, we were in the position of anticipating outcomes rather than relying on previous studies to know what to look for. A related consequence of the current state of research is that the research instruments themselves—survey questions and protocols—had to be developed from scratch to capture changes in these outcomes, largely without the benefit of drawing on previously validated surveys.

For these reasons, we designed the research strategy to be exploratory in nature—balancing our expectations for specific outcomes with opportunities for unanticipated benefits to emerge. As such, we adopted a mixed-methods approach, integrating both quantitative and open-ended qualitative prompts on surveys to all participants, and conducting interviews and focus groups with teachers and students at several sites. We hoped that taking this approach would enable us to document the impacts of engagement with the Learning Studios program, as well as to identify trends for further exploration and replication, notwithstanding the research challenges implicit in a highly diverse implementation sample.

2.1 Literature Review

To inform our methods and guide our expectations for teacher and student outcomes, we carried out a literature review to identify and summarize existing frameworks and learning outcomes associated with making and design-centered learning environments. We also looked to the literature to identify existing methods and measures for gathering evidence of these outcomes among learners. Our techniques for conducting the review included online searches of published manuscripts and white papers, as well as email exchanges, phone interviews, and in-person meetings with active researchers. While we identified several relevant frameworks, our review found few empirical studies, and little in the way of quasi-experimental designs. Figure 3 presents a summary of the findings that directly informed our design.

Agency by Design. Developed by a team of researchers at Harvard Project Zero, the Agency by Design framework defines maker empowerment as "a sensitivity to the designed dimension of objects and systems, along with the inclination and capacity to shape one's world through building, tinkering, re/designing or hacking" (Agency by Design, 2015). Key dimensions are sensitivity, which includes looking closely, exploring complexity, and finding opportunity; inclination and motivation to act; and the capacity and ability to be effective.

Learning Dimension Framework. Researchers at the Exploratorium have iterated on a "Learning Dimension Framework" through their investigations of museum visitors' engagement with tinkering and making in informal spaces. The four dimensions described in Petrich, Wilkinson & Bevan (2013) are engagement, intentionality, innovation and solidarity.

Next Generation Science Standards (NGSS) practices. Creativity Labs, in collaboration with the Maker Education Initiative, focused their research on NGSS practices, and found that the practices most applied in maker settings included: developing and using models; planning and carrying out investigations; and analyzing and interpreting data (Peppler, Maltese, Keune, Change & Regalla, 2015).

Democratization of Making. Researchers from the FabLab group at Stanford University, led by Paolo Blikstein, have focused on the intersection of digital fabrication and the democratization of making. Research describes their innovative approaches to identification and assessment of learner outcomes associated with maker spaces (Blikstein, Fields, Kabayadondo, & Martin, 2017).

Maker Mindset. AnnMarie Thomas, a leader in the maker education field and former director of the Maker Education Initiative, describes the maker mindset as a set of maker qualities including curiosity, playfulness, openness to risk, responsibility, persistence, resourcefulness, generosity in sharing, and optimism (Thomas, 2014).

Figure 3: Learning Frameworks Associated with Design-based Learning and Making

2.2 Outcomes Focus

Informed by the review of the literature as well as input from project staff and collaborators, we decided to focus our research on four main outcomes. For each outcome, we created a set of specific indicators based on the literature, and then developed instruments to capture student and teacher activity and progress on these indicators.

1. Engagement and persistence
   Indicators:
   - Students are excited about coming to school;
   - Students are eager to visit the Learning Studio;
   - A diverse range of students demonstrates their enthusiasm for the Learning Studio;
   - Students apply skills and perspectives from the Learning Studio to other aspects of life both in and out of school; and,
   - Students seek deeper understanding and knowledge beyond the minimum requirements.
2. Agency and ownership of learning
   Indicators:
   - Setting personal learning goals;
   - Seeking and responding to feedback;
   - Persisting to achieve goals despite setbacks;
   - Taking intellectual risks; and,

- Personalizing projects or assignments.

3. Empathy, collaboration and communication
   Indicators:
   - Awareness of the importance of taking perspective and understanding where others are coming from;
   - Ability to communicate effectively in a group work environment; and,
   - Ability to work effectively in a team, such as recognizing strengths that others bring, compromising and working through disagreements.

4. Design thinking and problem-solving
   Indicators:
   - Recognizing that the material world is designed;
   - Ability to identify problems to solve;
   - Ability to take perspective on one's own creation and those of others;
   - Demonstrating variation of efforts; and,
   - Ability to recognize failure and iteration as a regular part of the design process.

2.3 Research Design

To achieve our goal of documenting specific gains over time while also positioning the study to identify unanticipated outcomes, we crafted a research design that combined quasi-experimental and descriptive approaches. This approach would also enable us to capture participant input on program effectiveness and benefits. We gathered data from teachers and students using three methods: surveys, individual interviews, and focus groups, using the timeline shown in Figure 4.

Teachers were invited to complete four surveys: a baseline ("PRE") administered in the spring of 2016 as the program was launched and teachers were invited to join the program; a mid-course survey ("MID") at the start of the 2016-17 school year; and a post survey ("POST") administered at the end of the first Challenge project, in December of 2016. In May of 2017, teachers were invited to complete a brief follow-up ("FOL") survey. All teachers who completed the baseline survey were also invited to a brief phone interview at the start of the 2016 school year, to ask about their implementation plans and progress to date.

Students participating in the Learning Studio were invited through their teachers to complete a pre-survey as close as possible to their first visit to the studio, and a post-survey following the Challenge project in December of 2016. In May of 2017, teachers distributed a follow-up survey to students at the end of the second Challenge project.

In addition, a qualitative design was included to provide richer insights into change over time, and in particular to shed light on contextual factors related to Learning Studio implementation and outcomes. Ten schools were selected to serve as focal study sites. At each site, the lead teacher was interviewed individually via phone or Skype up to five times from October 2016 to June 2017. To gather student input, we also conducted virtual focus groups of up to five students at a time, from October to December 2016. Different students participated in each of the focus groups per site.

	April-Aug 2016	Sept 2016	Oct 2016	Nov 2016	Dec 2016	Jan-Apr 2017	May 2017
LEARNING STUDIOS PROGRAM							
Teachers	Onboarding	Project implementation at teacher discretion			Global Challenge	Project implementation at teacher discretion	Play to Learn Challenge
Students		Project work at teacher discretion			Global Challenge		Play to Learn Challenge
RESEARCH: ALL PARTICIPANTS							
Teacher Surveys	PRE	MID			POST		FOLLOW-UP
Teacher Interviews		Implementation plans					
Student Surveys		PRE			POST		FOLLOW-UP
RESEARCH: FOCAL SITES							
Teacher Interviews			X	X	X		X
Student Focus Groups			X	X	X		

Figure 4: Research Design

2.4 Teacher and Student Participants

In this section we provide an overview of the teachers and students who participated in the research component of the Learning Studios project. Details of the survey instruments and interview protocols used to gather data are described in the section that follows.

2.4.1 Teachers

A total of 95 teachers from the 60 Learning Studio sites completed one or more of the surveys. In most cases, a single "Lead Educator" per site engaged with the program, although at some sites multiple teachers participated. Table 1 shows response numbers for each survey, as well as the number of teachers completing pairs of surveys. Overall, 62 took the pre-survey, 40 responded to the mid-survey, 30 took the post-survey, and 27 completed the follow-up survey. Of teacher respondents, 20 completed both the pre and post surveys, and 18 completed both the mid and post surveys. Among teachers who completed the follow-up survey, 19, 17, and 15 had responded to the pre-, mid- and post-survey, respectively. Seventeen teachers were interviewed in September about their plans for the Learning Studio; and ten teachers took part in the focal site interviews.

Table 1: Number of Teacher Responses for Pre, Mid, Post and Follow-up Surveys

Totals:	62	40	30	27	
	PRE	MID	POST	FOL	Overlap
	✓		✓		20
		✓	✓		18
	✓			✓	19
		✓		✓	17
			✓	✓	15

Teachers were more or less evenly split across gender, and were fairly experienced as educators. About half (53%) of teachers taking the pre-survey were male; 45% were female. At the pre-survey, teachers reported an average of 13 years (sd=8.7) experience as educators, 6.5 years (sd=6.1) at their current organization, and 5.8 years (sd = 5.5) in their current role. Regarding prior making experience, two-thirds of teachers reported having led makerspaces or programs in the past. As detailed in Figures 5 and 6, the majority (89%) of teachers identified with Caucasian/White ethnicity; and 60% have earned graduate degrees.

Aboriginal	1.8%	1
African/ African American/ Black	3.6%	2
Asian/ Pacific Islander / Pacific peoples	1.8%	1
Caucasian / European / White	89.1%	49
Latino(-a) / Hispanic	9.1%	5
Middle Eastern	1.8%	1

Figure 5: Teacher Ethnicity

Associate/Advanced diploma	1.8%	1
Bachelor	20.0%	11
Bachelor Honours/Honours	10.9%	6
Masters	58.2%	32
Doctorate	1.8%	1

Figure 6: Teacher Education

At the pre-survey, teachers also provided information about the sites at which the Learning Studios were implemented. The majority (86%) were public/government schools; about 13% were private or independent schools and 2% were charter schools. Sites were roughly split evenly across suburban (44%) and urban (40%) settings, with 16% in rural locations. Participating schools enrolled from 120 to 2,030 students. Among US-based sites, on average 45% of students were eligible for free/reduced price lunch.

2.4.2 Students

A total of 1,276 students representing 52 teachers' classrooms completed at least one survey. As shown in Table 2, of the overall sample, 401 students, representing 21 teachers, responded to both pre and post surveys. Figure 7 presents key demographic information on students for both samples. At the follow-up, a total of 297 students' responses were obtained from 11 teachers' classrooms. Across all three time-points, 55 students completed both the pre-survey and follow-up survey; 50 completed the post- and follow-up surveys. In light of the attrition from pre-survey to follow-up, and due to the higher variance in program implementation in 2017, the focus of the quantitative results is on the primary implementation period, from September through December of 2016. When relevant, follow-up data are presented alongside the pre-post analyses.

Table 2: Number of Student Responses for Pre, Post and Follow-up Surveys

Totals:	1054	622	297	
	PRE	POST	FOL	Overlap
	✓	✓		401
	✓		✓	55
		✓	✓	50

NOTE: In this report, the label "Full Sample" refers to responses from the 1,276 students who completed at least one survey; "Final Sample" refers to the 401 students who completed both surveys.

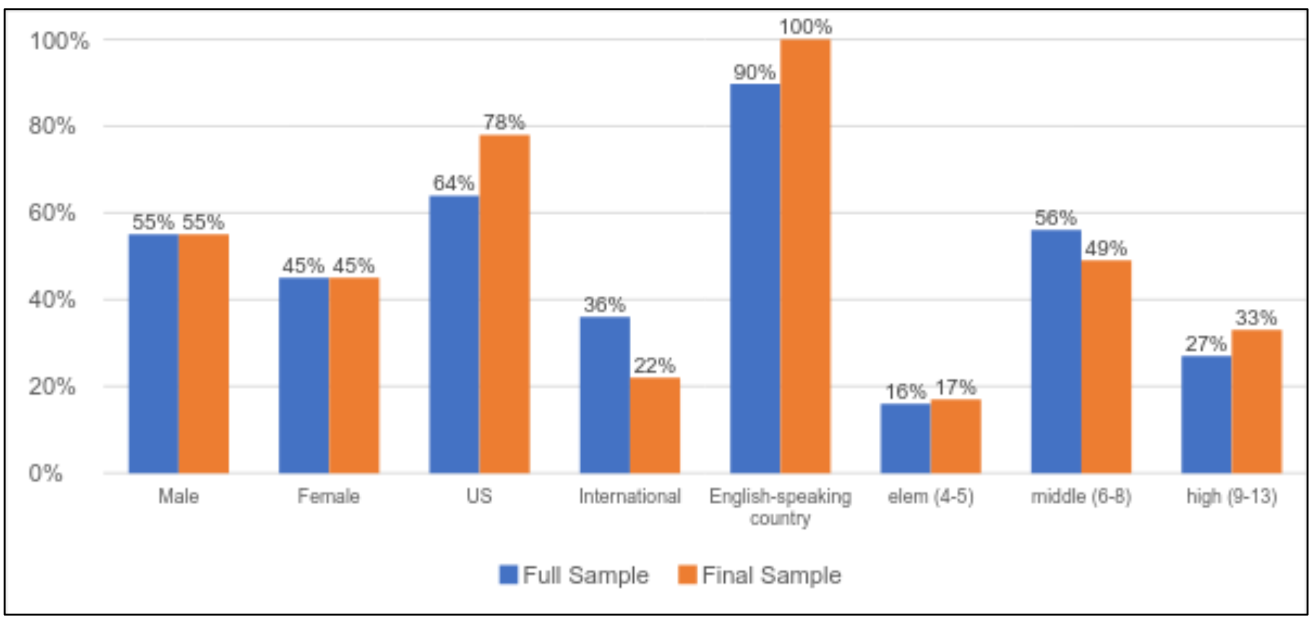


Figure 7: Student Demographics for Full and Final Samples

2.5 Data Collection: Surveys and Protocols

Figure 4 shows when each data collection method was implemented in the context of the Learning Studio program. All participants were invited to complete surveys at key points in the project timeline; at a small number of sites, teachers and students were invited to a series of interviews and focus groups. The instruments for data collection were all designed to tap into the key outcomes guiding the research, and to capture information regarding context of implementation. Descriptions of each survey and protocol with teachers and students are provided in this section, and the complete instruments are available from the project team on request.

2.5.1 Teacher Surveys

Pre-survey. The pre-survey for teachers, administered in the spring of 2016, was organized in several sections. The first targeted demographics and professional experience, as well as basic demographics related to school setting and enrolled students. The second section probed teachers' teaching style and instructional strategies in their regular classroom, and their planned strategies for the Learning Studio. In the third section, teachers shared their comfort levels with a variety of program-related activities and processes. The next section posed open-ended questions about teachers' prior experience both making personally and facilitating students' making activities, followed by a set of open-ended prompts about how teachers planned to use the Learning Studios equipment personally and with students. In a block of brief open-ended questions, teachers were asked to summarize the project in their own words, and to describe expectations such as anticipated challenges, struggles, personal growth, and ideal outcomes. A section focused on implementation asked teachers to describe the location and expectations for student involvement with the Learning Studio. Finally, teachers responded to open-ended prompts regarding their hopes for student learning and growth in the Learning Studio.

Mid-survey. Teachers completed the brief mid-survey in September 2016. Items asked about level of practice to date with the Learning Studio equipment and familiarity with the project guides provided by program staff. A set of open-ended questions asked teachers to share ways they anticipated students demonstrating engagement, agency, initiative and collaboration in the Learning Studio. They also indicated whether students with learning differences (e.g., diagnosed learning or attention issues) would take part in the Learning Studio, and to describe expectations for those students' experience vis-à-vis agency and engagement in the Learning Studio.

Post-survey. The post survey, administered in December after completion of the first Challenge project (Global Goals, Local Solutions), repeated items posed in the pre-survey and mid-survey, with the exception of the demographic and site questions. Wording was modified to be retrospective rather than prospective. For example, the question asking "Please describe some of the ways you anticipate students demonstrating engagement with the Learning Studio program" was changed for the post-survey to "Please describe some of the ways you saw students demonstrating engagement with the Learning Studio program."

Follow-up survey. The follow-up survey was administered in May 2017, after completion of the Play to Learn Challenge, the second culminating project. This short survey included a subset of selected-response items posed in the previous surveys regarding teachers' personal and instructional comfort with technology and making processes, and the frequency of Learning Studio activities such as public presentations of student projects and student access outside of regular school hours. The survey asked teachers about student participation overall and the projects completed, and included additional items regarding teachers' perspectives on student experience of the Learning Studio. The last set of questions asked teachers to reflect on the extent to which participation in the Learning Studio had an impact on them personally and on their students.

2.5.2 Student Surveys

Pre-survey. Students completed the pre-survey in school at the start of their Learning Studio experience. The first blocks of items asked students to select their site and teacher, and provide basic demographic data on gender and ethnicity. The second section probed students' identity as makers, asking to rate whether they see themselves as a designer or maker, and to describe previous experiences making, including what kinds of making they do, and with whom. In the third section, students rated their prior exposure to and current comfort levels with the Learning Studios equipment. Students were also prompted to share their ideas for how they might use the equipment. The next set of questions asked students to anticipate how much time they'd spend in the Learning Studio, as well as what they think they might learn, and what the experience will be like. Three items, adapted from Blikstein and colleagues (2017) were then posed to tap students' design thinking knowledge. The following set of items echoed the questions posed to teachers regarding comfort with making processes.

Post-survey. The post-survey repeated the same questions as the pre-survey, additionally asking which of the projects they completed, and what were the most important things they learned in the Learning Studio. An additional block of open-ended questions asked students to share their experience in the final project, including what they learned, what they found most challenging, most surprising, and what they enjoyed the most. Finally, students responded to Likert-style questions asking how often they took actions related to agency, collaboration, and persistence.

Follow-up survey. The follow-up survey repeated a subset of selected-response questions from the pre and post surveys, including students' identity as a maker and their comfort levels with technology and various making processes and skills. As on the post-survey, the follow-up survey also asked students how often they engaged in behaviors reflective of agency, collaboration and persistence in the Learning Studio.

2.5.3 Focal Site Protocols

Of the ten focal sites, nine were located in the United States and one was in Australia. At each focal site, one teacher took part in up to five semi-structured interviews between October 2016 and June 2017. The interview protocol included questions about how the project was going, which projects students tried and how they went, and what kinds of growth and learning the teacher was observing. Teachers were asked to share how students who might not thrive in traditional classroom environments were doing in the Learning Studio. Finally, teachers were asked to describe their current goals for student learning, whether they had changed since the previous conversation, and what their overall goals for the program were. The interviews lasted between 20 minutes and an hour, with substantial probing of responses by the interviewer. Interviews were audio recorded and transcribed for analysis.

The student focus group protocol guided conversations with small groups of students at each site, via Skype or other similar video conferencing platforms. The interviewer started off by asking students to share how it had been going so far in the Learning Studio, what it was like working in the Learning Studio, and what projects they were doing in the Learning Studio. Students were asked to describe what they had learned so far, what had been most challenging, and what surprised them the most. Whenever possible, students were prompted by the interviewer to provide concrete, specific examples, and the interview incorporated frequent probes for students to elaborate upon and clarify their input. In the later focus groups, students were asked to describe the final project as well. Student focus groups were audio-recorded for later analysis.

3. Results

As a whole, the surveys, interviews and focus groups generated data that helped us understand the extent to which the intended outcomes of the Learning Studio program had been attained. These data also provided insights into participants' perspectives on the value of the program, and enabled us to make connections between aspects of the implementation context and observed outcomes.

This section presents the results thematically, starting with information about the contexts of implementation and moving to students' and teachers' comfort with the specific technologies. Following these foundational results, we explore participants' growth and perspective within each of the four key outcome areas. We then present findings regarding the Learning Studio experience for students who have struggled in traditional classroom settings. Finally, we share results of analyses examining the intersection of instructional context and student outcomes.

Data from teacher and student surveys as well as interviews and focus groups are integrated within each section. Where multiple surveys posed the same question, we tested growth in two ways: by comparing responses on early (pre, mid) surveys to responses on later (post, follow-up) surveys; and by asking teachers and students to reflect on their experience in the Learning Studio. Unless otherwise specified, to test hypotheses regarding gains from early to later points in the program implementation, one-tailed paired-sample t-tests were performed. It is important to note that the small sample size for complete data sets, which was especially true for teachers, meant that reaching statistical significance required large gains. As this was an exploratory study, we opted to examine trends as well as statistically significant outcomes.

3.1 Background & Implementation Context

Because learning does not happen in a vacuum, context is as critical as the technologies and resources. For that reason, we focused a portion of the research on understanding several aspects of the context of implementation for the Learning Studios. Through open-ended questions at the very start of the program, we asked teachers to share their prior experiences with designing and making, whether personally or as educators. Other questions asked teachers to indicate their pedagogical approaches and priorities. We also placed importance on knowing how often students visited the Learning Studio, and what kinds of projects they worked on while there. Implementation model was another aspect of context we considered.

Implementation Characteristics. As expected, we found tremendous diversity in the settings in which students engaged with the program and the ways that the Learning Studio was being implemented at each school. From grade level to socioeconomic markers to teachers' own prior experience with making and technology, participating classrooms differed substantially. In some schools the primary implementation was as an afterschool program. Others implemented the Learning Studio in the context of an existing design course, such as Project Lead the Way, whereas some teachers allocated an hour a week within a math or science class. In the majority of cases, students' participation was required as part of their school curriculum, however at several sites use of the Learning Studio was voluntary or part of an afterschool club.

Educator Backgrounds. We also observed a great deal of variety in the backgrounds that teachers brought to the Learning Studio. An early analysis was carried out to qualitatively group teachers into categories based on their personal and professional experiences with maker and design-centered learning. The entire set of responses, both quantitative and qualitative, were used to holistically generate categories. This process yielded four groups of teachers, in which no attempt was made to create evenly sized groups. A sampling of responses from three of the survey questions are included in Appendix B for each group.

Group 1: Beginner (19 teachers)

- enthusiasm and buy-in for the Learning Studio project
- little background in making or design thinking principles or strategies
- did not identify design thinking as an area of growth for their students in the Learning Studio

- tended to focus on technology skills

Group 2: Emerging (7 teachers)

- some personal experience with making
- little/no experience facilitating students to make
- did not express awareness of design thinking principles or strategies

Group 3: Intermediate (14 teachers)

- personal and professional experiences with making
- experience facilitating student making projects, including robotics clubs and other initiatives
- design thinking did not figure prominently in responses

Group 4: Advanced (12 teachers)

- evidenced knowledge and experience of the design process
- situated making within a larger culture of pedagogy related to project-based learning

Pedagogy and Instructional Strategies. We further explored context by asking teachers about their pedagogical approach, and whether their approaches in their classrooms differed from their teaching in the Learning Studio. Overall, teachers described fairly progressive approaches, and a desire to engage students actively and in authentic challenges. One source of evidence for this finding was the descriptions of their teaching style that teachers provided on the pre-survey. Among the common themes that emerged in those responses were:

Emphasis on collaboration (mentioned 12 times):

- “I have a collaborative classroom where every student gets the opportunity to participate. I use small group instruction and stations on a daily basis. I also use technology on a regular basis."
- “I am a teacher that encourages collaboration and cooperation. I encourage my students to think out of the box. I encourage the use of effective technology to facilitate, enhance, support and enrich their learning.”
- “Hands-on, lots of inquiry-based, small group instruction and collaborative, student-led learning /problem solving.”

Emphasis on problem-solving (mentioned 11 times):

- “I try to find out with student a precise maths topic by reasoning and problem solving. I do not share with students a new theory from zero, but I want them to reach the focus point by themselves.”
- “My role as an educator is a facilitator of learning. I try to implement as many opportunities for personalized learning including facets of voice, choice, pace, path, and place in my teaching. I rely on an environment that is very much student-led as well as try to foster a collaborative environment around problem solving.”

- "I like students who are able to find solutions to problems using all the resources (technological or not) that they have in the class. I like to do a short introduction before starting the class to explain the goals that we have during the session and help the students to learn how to find themselves the solutions. Sometimes you have to explain concepts, but they should learn by doing."

Hands-on and interactive approaches:

- "I like students to be able to be hands-on. I find that students, especially middle school students, learn best by doing. This is especially true when it's something they are interested in. I try to limit the lectures to providing them with the background knowledge they need, and then give them the opportunity to explore and learn."
- "Hands-on, lots of inquiry-based, small group instruction and collaborative, student-led learning /problem solving."
- "I am a very interactive teacher! I try to avoid sit and get teaching by creating activities that are engaging and meaningful for students. Technology plays an important role in this level of engagement and I enjoy allowing my students to extend their thinking through the use of technology. In addition to working with students in a whole group setting, I also pull students for small group instruction in order to provide more individualized instruction. All of these components fit well within the PBL framework, which is an integral part of teaching and learning."

Teachers' endorsement of facilitative approaches to instruction also came through when we asked them to report how often they use specific instructional strategies in their regular classroom, and in the Learning Studio. Table 3 presents their pre-post responses, ordered by the proportion of teachers who reported using the strategy or not in each setting. Generally, instructional strategy uses were ranked similarly by teachers for the classroom and Learning Studio. However, teachers tended to rank overseeing collaborative activities more highly for the Learning Studio than in their classroom, where the top-ranked strategy pertained to facilitating student discussions. Notably, across the board, participating teachers selected instructional strategies consistent with design-based learning, for instance with tests and direct instruction ranked toward the bottom of the list.

Table 3: Teachers' Rankings (1 through 12) of Instructional Strategy Use in Their Classroom and the Learning Studio

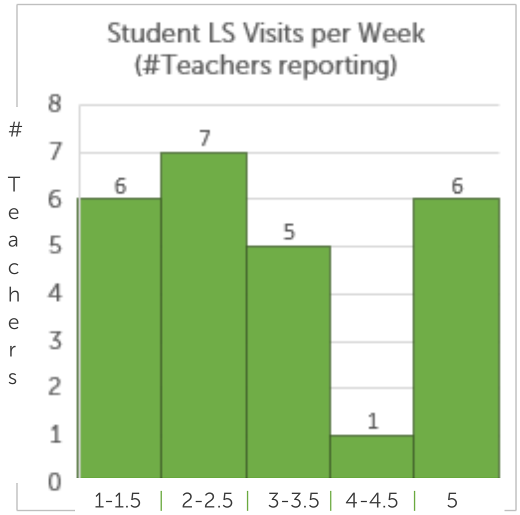
Instructional Strategy	Classroom Strategies		Learning Studio Strategies	
	Pre (n=62)	Post (n=30)	Pre (n=62)	Post (n=29)
Demonstrate uses of technology	2	1	2	1
Facilitate student discussions of approaches to solving problems, explanations of their thinking, or open-ended questions	5	2	3	2
Demonstrate a concept using graphics, computer, projector	1	3	4	3
Set up and monitor or supervise cooperative or collaborative learning activities	4	4	1	4
Observe or monitor student-led whole-group class discussions or demonstrations	7	6	6	5
Provide individual or small group tutoring as needed during individual seatwork or small group activities	3	5	7	6
Demonstrate a concept using physical artifacts or models	6	7	5	7
Provide remedial or enriching instruction to a pull-out group while the rest of the class works on assignments	10	8	8	8
Lecture, perhaps occasionally soliciting student input or using board/overhead to highlight a key term of present an outline	8	9	9	9
Administer a test or quiz	9	10	10	10
Work on administrative tasks, such as grading, while students work on assignments individually	12	12	12	11
Lead students in recitation, drills, or question-and-answer sessions	11	11	11	12

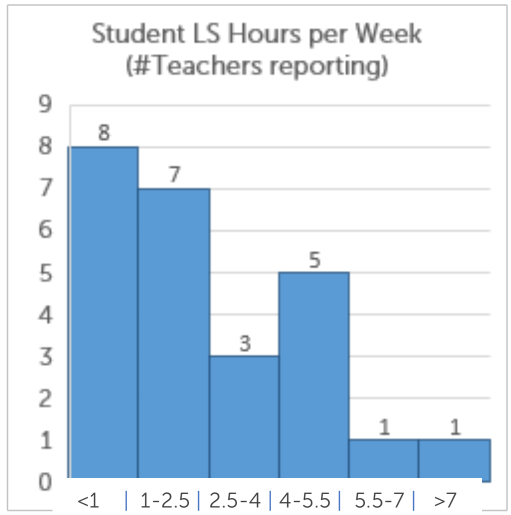
Because we were curious to see whether teachers' instructional strategies would change over the course of their Learning Studio implementation, we asked for these rankings at the post-survey as well. We also posed the open-ended question about teaching style again at the post-survey. As Table 4 shows, we found that teachers' ratings remained fairly constant from pre to post. Similarly, we did not observe shifts in teachers' descriptions of their teaching style over the course of the program. However, one interesting finding was the increase in order of importance of the strategy "Facilitate student discussions of approaches to solving problems, explanations of their thinking, or open-ended questions" in teachers' regular classrooms. Among teachers completing both pre and post surveys, on average this strategy ranked 5th at pre, and moved up to 2nd at post. With respect to instructional strategies specifically anticipated or used in the Learning Studio, notable changes from pre to post include a drop in importance, from 1st to 4th place, of "Set up and monitor or supervise cooperative or collaborative learning activities". While an early trend, and subject to confirmation in future studies, this outcome might suggest that teachers discovered a need to provide more support around the technology than originally anticipated.

In interviews, several teachers spoke to the ways that educating in a Learning Studio environment called for a different approach to instruction—one in which they did not need to know all the answers, and in which students could also feel free to try new things. As one high school teacher reflected when asked how to bring other teachers onboard, "Accepting that mindset, and telling everyone from the beginning that we don't expect staff to know everything. It sounds really simple but when you acknowledge that with the kids it starts the relationship off differently than 'I know everything and you don't'."

With regard to pedagogy and instructional approaches, there was some evidence that the early nature of instruction in design thinking means that teachers often have to rely on their own observations to identify typical learning challenges, and to craft effective instructional strategies in response. For example, an elementary school teacher reflected on how she discovered that students' understanding of 3D dimensional shapes was a key determinant in whether they could engage successfully in 3D modeling. "I realized that before we can talk about 3D modeling we really needed to talk about three-dimensional shapes-- which are [state] standards all the way through. Even the little kids need to understand that objects look different from different perspectives. I give the example in my class of a teddy bear. If you were to draw a teddy bear with shapes, you'd probably use a circle for the head, maybe an oval for a body, some little circle ears, maybe a triangle nose, right? You can imagine what those shapes look like. But then if I tell you to draw the teddy bear looking at it from the top down, it becomes harder -- because the top of the teddy bear doesn't look like a teddy bear. (...) I guarantee whoever's struggling with that are the same kids who will struggle with the 3D modeling. I think [those foundational skills] are the lowest level scaffolding before students can be successful in the 3D modeling piece."

Student Exposure to the Learning Studio. The quantity and quality of students' exposure to the Learning Studio was another key aspect of context to consider. To assess exposure, we asked teachers how often students visited the Learning Studio and how long they spent there. We also asked which of the project guides provided by the program staff teachers opted to implement with their students. Figures 8 and 9 present data showing weekly exposure to the Learning Studio. For the majority (18) of teachers who responded, students typically made up to 3.5 visits to the Learning Studio each week, and spent up to 4 hours there weekly. However, a third (6) of the teachers indicated that their students visited about once a week. In other words, over a three-month period, that group of students would have spent about 15 hours total in the Learning Studio—a relatively short amount of time to expect dramatic learning and growth.





Figures 8 and 9: Teacher-reported Student Weekly VISITS and HOURS Spent in Learning Studio

In many cases, students chose to access the Learning Studio beyond the times allotted in class. As one teacher shared, "Yesterday at lunch I had seventy kids in here! They love their project and want to work on it." And another, "Even outside of their class time, students come in to work on their independent project. Probably more than twenty students every morning doing some kind of independent project." A middle-school teacher shared, "They like the Learning Studio because it gives them more freedom. (…) They now know that they can come in there and not only have the equipment but also the ability to do something. I think the freedom that they get really makes their eyes light up and makes them want to come."

Because teachers were at liberty to choose which projects, if any, to implement as part of the Learning Studio, exposure to the Projects is another important consideration in making sense of the students' responses. As can be seen in Figure 10, an important finding was that teachers implemented only a few of the Learning Studio projects. Although the Global Goals, Local Solutions project was strongly encouraged, only about two-thirds of teachers implemented it with their students. Specifically, at the post survey, twenty-eight teachers responded to the question about Projects completed. On average, their students completed two of the projects provided by the Learning Studio program, with a range from zero to five projects completed. Because different samples of teachers responded to the post and follow-up surveys, the number of times a project was completed vary.

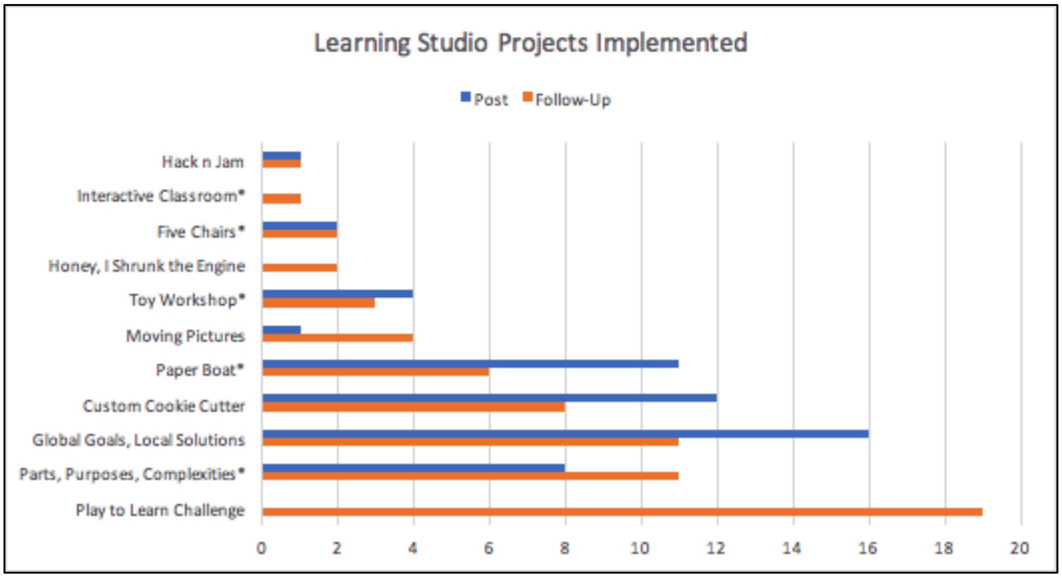


*Figure 10: Learning Studio Projects Implemented by Participating Teachers *'s denotes "projects of the week" that teachers were encouraged to use in the fall leading up to Global Goals, Local Solutions Challenge.*

3.2 Technology Use, Comfort & Related Skills

In this section, we look at the extent to which teachers and students used the advanced technologies in the Learning Studio, how their comfort with these technologies changed over time, and the skills they developed in using them over the course of the program.

Practice and Comfort with Learning Studios Equipment. Not surprisingly, one of the impacts of the Learning Studio was to increase access for teachers and students to advanced technologies. From September (mid) through December (post), we saw significant gains in teachers' practice using the Sprout and 3D printer technology (Table 4A). The same was true on average for students from pre to post surveys (Table 4B). Another view of the same data shows shifts from pre to post, and from pre to follow-up surveys, of the distribution of students across the response options. Figures 11 through 14 reveal substantial shifts from "not yet" or "not sure what this is" responses into the "once or twice" through "many times" responses. The proportion of students who had used the Sprout at least once increased from 23% to 65% from pre to post. For the 3D printer, the increase was from 29% to 58%. At the same time, at post and at follow-up, a high proportion of students shared that they had not yet used these technologies (39%-51%).

One possible explanation for this finding, which emerged in interviews with teachers, is that the ratio of technology to students made it challenging to give everyone access. Teachers and students noted that time was also a factor, especially for the 3D printer, which can require many hours to print a single design. For this reason, students had to rotate access, and it is possible that for students working in a group, they were not the person designated to work directly with the printer. At one high school, students explained that because so demand was so great for the 3D printer, a few students were responsible for all printing. In that scenario, these results may under-represent the extent to which students had the opportunity to carry out their design work using the Learning Studio resources. Another explanation for why such a large proportion of students did not report using the Sprout or 3D printer is that while the technology was a valuable resource for teachers, there were many options for introducing students to design thinking and making. For instance, the Parts, Purposes & Complexities project, based on the thinking routine developed by Agency by Design (2015), that several teachers implemented with students did not require the use of technology. As such, those students may have still benefited from the program, even if they had limited hands-on experience with the technologies.

Table 4A: Teachers' Use of Learning Studio Equipment+

	MID		POST		
	Mean	Sd	Mean	sd	*t*
Sprout	2.86	1.283	3.77	1.066	$t(21)=3.578^{***}$
3D printer	2.86	1.352	4.05	1.071	$t(20)3.627^{***}$
Laptop	2.64	1.329	3.55	1.371	$t(21)=3.177^{**}$

+5-point scale from 1 ("None yet") to 5 ("A lot")

Table 4B: Students' Use of Learning Studio Equipment+

	PRE		POST		FOL		n=401	n=43
	Mean	Sd	Mean	sd	Mean	sd	PRE-POST	PRE-POST-FOL
Sprout	2.06	.935	3.02	1.168	3.07	1.486	$t(400)=14.092^{***}$	$F(1.85, 77.82) = 16.051^{***}$
3D printer	2.37	.824	3.01	1.107	3.00	1.27	$t(400)=10.593^{***}$	$F(1.56, 65.45) = 12.316^{***}$

+ 5-point response scale: 1 ("Not sure what this is") – 2 ("Not yet") – 3 ("Just once or twice") – 4 ("A few times") – 5 ("Many times"); For pre and post columns, descriptive statistics are for the set of complete pre-post responses; for the follow-up column, descriptive statistics are for the set of complete pre-fol responses.

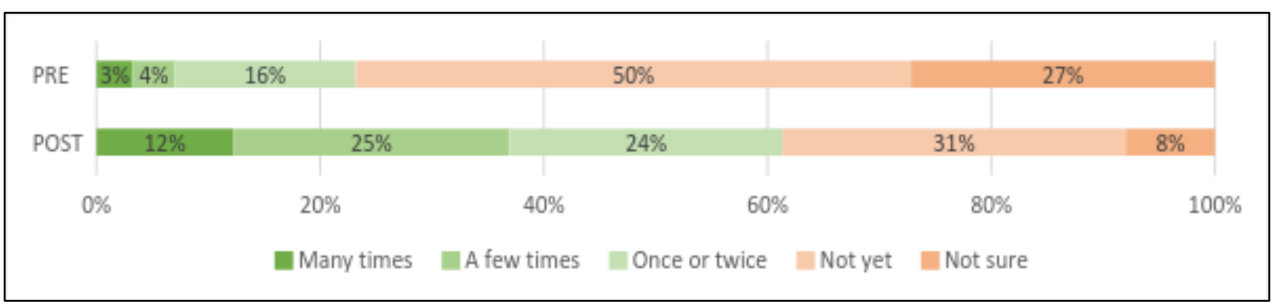


Figure 11: How often did students use the Sprout (PRE-POST) n=401

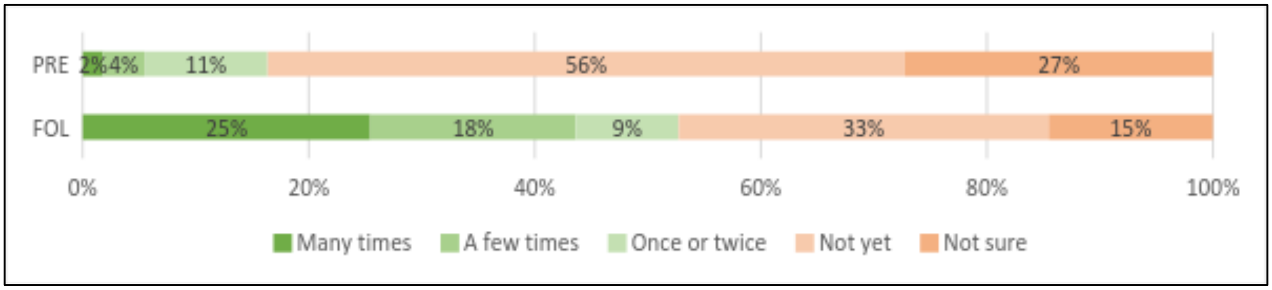


Figure 12: How often did students use the Sprout (PRE-FOL) n=55

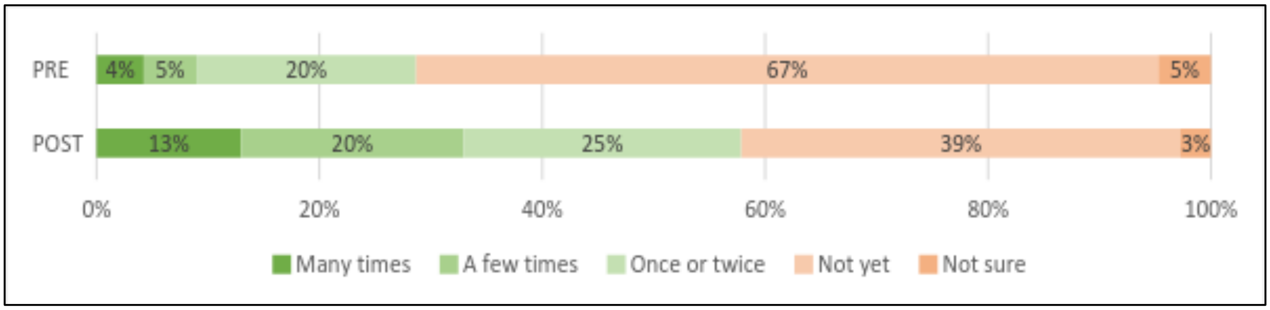


Figure 13: How often did students use the 3D printer? (PRE-POST) n=401

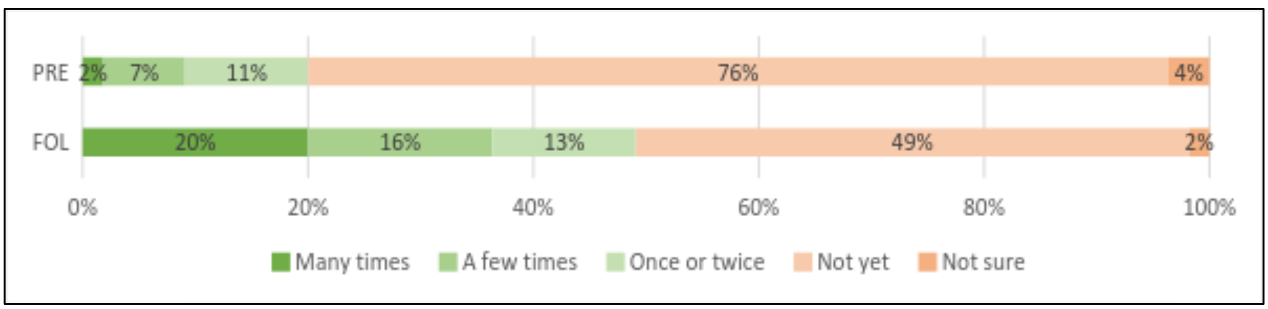


Figure 14: How often did students use the 3D printer? (PRE-FOL) n=55

In addition to understanding how often teachers and students used the technology, we were also interested in how their comfort changed over time. We found substantial increases for teachers and students. For students, this comfort extended beyond using the technology to higher levels of comfort teaching others to use it and even for fixing technical problems that might arise.

Tables 5 and 6 summarize the relevant survey responses for teachers and students. Over the first six months of their participation in the Learning Studio, teachers' personal comfort with the technology increased significantly. To examine trends in students' levels of comfort, we first removed those who reported not having used the technology yet from analyses. Among students who had used the Sprout or 3D printer at least once by the post or follow-up survey, we found significant gains for all areas. (Appendix B presents results for the full sample, without removing students who didn't report use of the Sprout or 3D printer). Among the 24 students who completed all three surveys and used the technology at least once, comfort levels increased from the start to the end of the school year, and in particular from the post to the follow-up, suggesting that additional exposure and perhaps additional time matters for building comfort and knowledge of the technology. Despite small sample sizes, these results still registered as statistically significant.

Table 5: Teachers' Comfort with Learning Studios Equipment+

Mean	sd		Mean	sd	Mean	sd		
FOL			MID		POST		MID-POST (n=20)	PRE-POST-FOL (n=13)
3.15	.555	Sprout	2.10	1.119	3.35	.587	$t(19)=5.784^{***}$	$F(1.69, 20.27) = 15.572^{***}$
3.46	.660	3D printer	2.50	1.000	3.40	.598	$t(19)=4.414^{***}$	$F(1.46,17.478) = 11.531^{**}$
FOL			PRE		POST		PRE-POST	PRE-POST-FOL
		Sprout++					n=246	n=24
		- Use	3.17	1.456	3.81	.982	$t(245)=6.941^{***}$	
3.96	1.083		2.88	1.513	3.50	1.319		$F(2,46)=5.781^{**}$
		- Teach	2.41	1.349	3.15	1.171	$t(245)=7.721^{***}$	
3.58	1.530		2.04	1.429	2.67	1.308		$F(2,46)=10.191^{***}$
		- Fix	2.37	1.274	2.78	1.184	$t(245)=4.863^{***}$	
3.37	1.469		1.96	1.122	2.37	1.209		$F(2,46)=12.570^{***}$
Mean	sd		Mean	sd	Mean	sd	PRE-POST	PRE-POST-FOL
FOL		3D printer++	PRE		POST		n=232	n=23
		- Use	3.19	1.437	3.88	1.012	$t(231)=7.385^{***}$	
3.65	1.112		2.83	1.586	3.48	1.238		$F(2,44)=3.431^{*}$
		- Teach	2.41	1.342	3.21	1.239	$t(231)=8.395^{***}$	
3.22	1.565		2.09	1.564	2.70	1.521		$F(2,44)=4.156^{*}$
		- Fix	2.26	1.211	2.68	1.215	$t(231)=4.912^{***}$	
3.09	1.535		2.04	1.364	2.17	1.154		$F(2,44)=5.237^{**}$

+5-point response scale ranged from 1 ("not at all comfortable") to 5 ("totally comfortable"). For teacher responses: in pre and post columns, descriptive statistics are for the set of complete pre-post responses; for the follow-up column, descriptive statistics are for the set of complete pre-fol responses.
++The first row for each result shows descriptive and test statistics for teachers with complete mid-post response sets; the second row shows statistics for teachers with complete mid-post-fol response sets.
$^{***}p<.001$, $^{**}p<.01$, $^{*}p<.05$

Table 6: Changes in Student Comfort Using, Teaching and Fixing Technology+,++

	Mean	sd	Mean	sd	Mean	sd		
	PRE		POST		FOL		PRE-POST	PRE-POST-FOL
Sprout+++							n=246	n=24
- Use	3.17	1.456	3.81	.982			$t(245)=6.941^{***}$	
	2.88	1.513	3.50	1.319	3.96	1.083		$F(2,46)=5.781^{**}$
- Teach	2.41	1.349	3.15	1.171			$t(245)=7.721^{***}$	
	2.04	1.429	2.67	1.308	3.58	1.530		$F(2,46)=10.191^{***}$
- Fix	2.37	1.274	2.78	1.184			$t(245)=4.863^{***}$	
	1.96	1.122	2.37	1.209	3.37	1.469		$F(2,46)=12.570^{***}$
	Mean	sd	Mean	sd	Mean	sd	PRE-POST	PRE-POST-FOL
3D printer+++	PRE		POST		FOL		n=232	n=23
- Use	3.19	1.437	3.88	1.012			$t(231)=7.385^{***}$	
	2.83	1.586	3.48	1.238	3.65	1.112		$F(2,44)=3.431^{*}$
- Teach	2.41	1.342	3.21	1.239			$t(231)=8.395^{***}$	
	2.09	1.564	2.70	1.521	3.22	1.565		$F(2,44)=4.156^{*}$
- Fix	2.26	1.211	2.68	1.215			$t(231)=4.912^{***}$	
	2.04	1.364	2.17	1.154	3.09	1.535		$F(2,44)=5.237^{**}$

+5-point response scale: 1 “Not at all comfortable”; 2 “Not very comfortable”; 3 “Somewhat comfortable”; 4 “Comfortable”; 5 “totally comfortable”.
++This analysis includes only those students who reported having used the Sprout or 3D Printer at least once by the time of the POST or FOL survey.
+++The first row for each result shows descriptive and test statistics for students with complete pre-post response sets; the second row shows statistics for students with complete pre-post-fol response sets.
$^{***}p<.001$, $^{**}p<.01$, $^{*}p<.05$

Regarding teachers’ comfort facilitating students’ use of the technology, from pre-survey to post-survey, teachers indicated increases. At the follow-up, these trends remained statistically significant, as shown in Table 7.

Table 7: Teachers' Comfort Facilitating Students' Use of Learning Studios Equipment+

	MID		POST		FOL		n=20, 19	n=13
	Mean	sd	Mean	sd	Mean	sd	MID-POST	MID-POST-FOL
Sprout	2.15	1.226	3.20	.616	3.46	.519	$t(19)=4.273^{***}$	$F(1.163,13.955)=15.857^{**}$
3D printer	2.63	1.165	3.32	.749	3.46	.660	$t(18)=2.822^{*}$	$F(1.77,21.238)=3.973^{*}$

$^{+}$ For pre and post columns, descriptive statistics are for the set of complete pre-post responses; for the follow-up column, descriptive statistics are for the set of complete pre-fol responses.
$^{***}p<.001$, $^{**}p<.01$, , $^{*}p<.05$

Teachers' own comfort with the technology, and perhaps their comfort in not having mastered the technology, seemed to influence students' growth and comfort. "In the beginning, I felt like I needed to really know how to do all the different things [the Sprout and 3D printer] could do. And I felt like I wasn't able to make refined models. But I found that as long as I didn't have that expectation of myself, the kids weren't blocked by that barrier." Discovering techniques for using the technology effectively also made a difference, "Someone finally told me that the reason [3D printing] is so hard is that your model is not touching the bottom in all four corners. Once I started doing that I had no problems printing. So just those little tips and tricks were helpful. And as we discovered those things through trial and error, I think it made all the kids feel more comfortable."

The focal site teachers also reflected a variety of approaches to troubleshooting the technology, and these differences appeared tied to prior experience leading maker-type spaces. One experienced teacher explained, "I don't teach 3D printing and I don't teach how to use the Sprout. They figure it out. I really like that component. I feel like they are fed so much from us and this is a place where they can take initiative." In contrast, in one interview another high school teacher shared that students hadn't accessed the printer for a month, because it wasn't working and she hadn't had time to fix it. These patterns may be exacerbated in schools with limited resources, where the consequences are greater if valuable technology breaks; teachers in those situations may be reluctant to give students free reign to figure out solutions given the sense of risk entailed.

Changes to Technology Skills. Beyond growing in their comfort with the technology, teachers and students also developed skills related to using the equipment and software. In later sections we describe how the Learning Studio experience drew upon a broad array of competencies for teachers and students; in this section we focus closely on specific technology-related skills.

The surveys included questions about two specific technology skills related to making: recording and editing an audio or video recording, and creating a digital 3D model of an object. Results on these skills were mixed. For teachers, significant improvements were found for creating a 3D model of an object, but not for working with audio or video files. Among students, we looked at middle school and high school students' results separately and found distinct differences, shown in Table 9. Whereas middle school students reported a marginally significant increase from pre to post for working with audio and video files, the increase was not as notable for high schoolers. In contrast, comfort creating a digital 3D model remained nearly constant from pre to post for middle schools students, while significant gains were found among high school students. For students who completed all three surveys, as shown in Table 8, trends were both positive and significant despite a relatively small sample size. As we found with students' comfort using the technology, these skills also appear to benefit from extended access and engagement with the Learning Studio, as demonstrated by continuously increased values from September 2016, to December 2016, to May 2017. One explanation for this finding is that more of the provided projects explicitly called for 3D modeling than for media production, which was often featured as an optional documentation element of the projects.

Table 8: Overall and Grade-Level Pre-Post Changes in Student Comfort with Technology Skills

	PRE		POST		FOL			
Tech Skill	Mean	sd	Mean	sd	Mean	sd	PRE-POST	PRE-POST-FOL
Recording and editing an audio or video recording								
All (n=305)	2.72	1.004	2.84	1.031			$t(303)=1.790^{*}$	
All (n=38)	2.66	.994	2.79	1.044	3.24	.751		$F(2,74)=6.421^{**}$
Middle School (n=178)	2.67	1.035	2.81	1.067			$t(177)=1.591^{+}$	
High School (n=126)	2.79	.958	2.87	.980			$t(125)=$ .729 (ns)	
Creating a digital 3D model of an object								
All (n=305)	2.70	1.059	2.79	1.059			$t(303)=1.479^{+}$	
All (n=38)	2.26	1.057	2.63	1.125	2.92	1.050		$F(2,74)=6.990^{**}$
Middle School (n=178)	2.97	1.008	2.99	.977			$t(177)=.347$ (ns)	
High School (n=126)	2.33	1.018	2.51	1.108			$t(125)=1,878^{*}$	

$^{+}$Response scale ranged from 1 ("Low") to 4 ("High")
** p<.05; ** p<.01; $^{+}$ p<.10*

As with technology use, we were curious whether teachers' comfort facilitating students' skill growth increased over the duration of the program. We found marginally significant increases for working with audio and video files, $t(14)=1.382$, $p=0.094$, and significant gains facilitating students to create a digital 3D model of an object, $t(14)=2.982$, $p=0.005$. At the follow-up, this latter trend remained statistically significant. The follow-up survey also included opportunities for teachers to indicate their agreement with a variety of statements about the program and their students' experience of it. Despite the inclusion of a "neutral" option on the 5-point scale, 100%

of teachers agreed that their students learned valuable skills through their participation in the Learning Studio, with 63% expressing strong agreement. Among teachers who implemented the Play to Learn challenge with their students, strong agreement with this statement was at 88%.

The conclusion that students learned more about technology was further evidenced in the open-ended responses on the post surveys. We asked students to briefly describe what they had learned in the Learning Studio. Students shared a variety of areas in which they had experienced growth. More than two in five (42%) cited technology as a learning area. Their responses ran the gamut from basic skills—e.g., "How to create my own things with a 3D printer"—to awareness of more robust growth—e.g., "I've learned how to work better in groups, how to use modern technology like the sprout computer, solve problems without the teachers, work in different ways." A number of responses focused on coding and programming, without reference to the equipment, e.g., "I have mostly learned a lot about computer programming in this class using the computers and laptops," and "I learned how codes work and different types of codes. I also learn more about programs like Python, Java, C++." Projects related to coding were among the additional project guides that accompanied the Play to Learn Challenge.

Gains in technology skills were also described by teachers in open-ended survey responses inquiring into outcomes of the Learning Studio program. One middle-school teacher wrote, "So far, I would say the biggest success for my students is that they have become far more proficient in 3D design with Auto-CAD-type software. Almost all of my 180 students in the last trimester were able to successfully design/build different models that followed specific guidelines. None of them were able to do that prior to receiving teaching and practice that involved the Learning Studio." Another teacher cited "greater knowledge, engagement and usage of technological devices, improved digital literacy," among the key outcomes. In interview conversations with teachers, we also found examples of ways that working with the Learning Studio technologies prompted students to build their skills in related standards. "One thing I noticed is strengthened by the modeling is measurement. I think that their concept of what's a millimeter, how big something is, has definitely been strengthened by the 3D modeling. I have one group that's making a solar-powered car …The first [part] they made…they ended up having to print a bigger one. They figured out that 3cm is small! Now they can visualize that, which makes it easier for things like word problems or some of those higher-order Common Core math problems."

3.3 Identity and Confidence as Designers and Makers

This section presents the third and final area of inquiry that sets the backdrop for exploring the key outcome themes. We looked into the ways that the Learning Studio experience helped teachers and students grow in their self-confidence and identity as designers and makers. As with the other topics, we approached this question through a variety of survey questions and interview prompts. Overall, we found evidence that while many students developed a stronger sense of themselves as makers and designers over the course of the project, this was not a universal outcome. This result differed by grade level, with older students reporting relatively higher levels of growth than younger students, with relatively more younger students nevertheless identifying as designers or makers.

Changes in Students' Sense of Identity as Designers and Makers. From the surveys, we learned that the change in sense of self as designer or maker from pre to post survey was positive and significant on average for high-school students, but not for middle or elementary students, though the latter showed a positive trend. It is noteworthy, given prior research on declines in motivation and self-efficacy as students progress from elementary through to middle and high school, that at the post survey, nearly two-thirds (64%) of elementary students considered themselves makers whereas 39% of middle schoolers and 53% of high schoolers felt the same (Table 9). Moreover, as shown in Table 11, among high school students who completed all three surveys, the average rating for this question at the follow-up was higher than at pre or post, though not statistically significantly so.

A closer look at students' pre-post responses to the question, "Do you see yourself as a designer or maker" reveals that at the pre-survey, 85 students chose the highest point on the scale and therefore could not show higher responses at the post survey. However, of the remaining 316 students, 36% gave a higher answer at post than at pre; 64% gave an equal or lower response. To further explore this finding, we carried out the analysis again, including only students who reported making at least 10 visits to the Learning Studio between pre and post surveys. Results were identical to the full sample, with 36% indicating growth in their identification as a designer or maker. Responding to a related question that appeared only on the follow-up survey, four in five students (80%) felt that taking part in the Learning Studio was helpful for seeing themselves more as a maker or designer, as shown in Figure 16.

Table 9: Proportions of Students Who Consider Themselves to be Makers or Designers

Grade Band		PRE	POST
Elem (grades 4-5; n=69)	No	9%	12%
	Maybe	33%	25%
	Yes	58%	64%
Middle (grades 6-8; n=198)	No	28%	27%
	Maybe	29%	34%
	Yes	42%	39%
High (grades 9-13; n=134)	No	20%	17%
	Maybe	37%	30%
	Yes	43%	53%

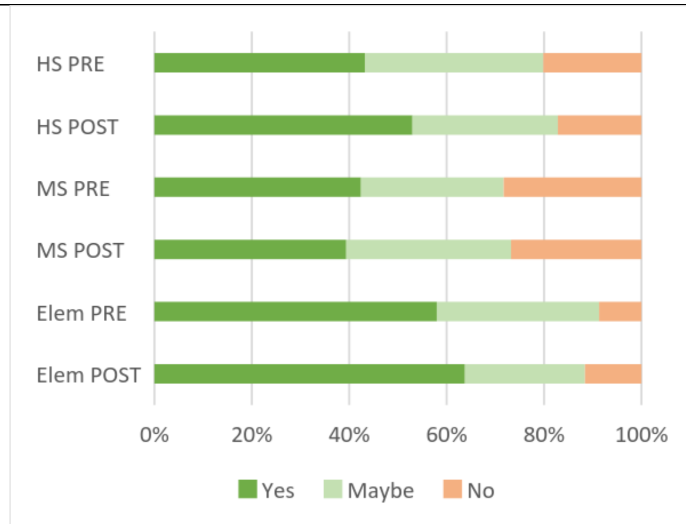


Figure 15: Percentages of Students Who Consider Themselves to be Makers or Designers, by Grade Level

Table 10: Changes in Students' Maker Identity+

	PRE		POST		FOL			
Are you a Maker or Designer?	Mean	sd	Mean	sd	Mean	sd	PRE-POST	PRE-POST-FOL
All	3.37	1.181	3.44	1.176			*t*(400)=1.279 (ns)	
Elementary School (69)++	3.75	1.077	3.88	1.078			*t*(68)=.869 (ns)	
Middle School (n=198)++	3.24	1.246	3.19	1.211			*t*(197)=-.563 (ns)	
High School (n=134)	3.37	1.095	3.58	1.085			*t*(133)=2.634**	
High School (n=35)	3.40	1.117	3.54	1.010	3.71	1.073		*F*(1.468,49.902)=1.687 (ns)

+Response scale: 1 (Not at all) - 2 (Not so much) – 3 (Maybe) – 4(I guess so) – 5(Yes).
++ For elementary and middle school students, size of complete pre-post-fol data sets (n=4 for each) was too small to analyze.
** $p<.01$

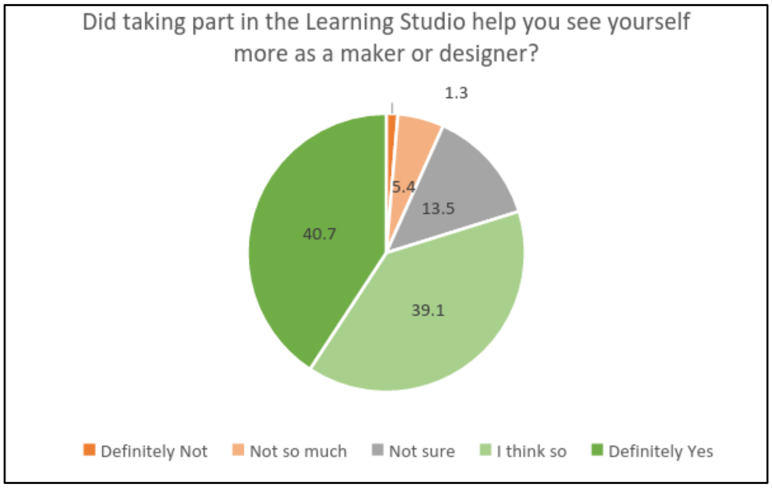


Figure 16: Learning Studio and Making Identity (FOL)

In addition to asking students to select a response option to the question about their identity as makers and designers, we asked them to elaborate on their response choice. To qualitatively explore shifts in identity, we compared the pre and post responses of the 381 students who completed both surveys. About one in six students (16%) showed some increase in identification, with several describing marked changes. Examples are shown in Table 11. Our analyses also revealed a tendency for some students to interpret the question in the context of a career preference, or in relation to fashion design rather than more broadly. For example, "I do like to make things but that's not what I would like to do as a career" or "A designer is someone who creates many different pieces, whether it involves designing homes or designing fashion." Because of this disconnect between the intent of the question and its interpretation, results may not be fully reflective of the ways that students developed greater confidence in their capacity to design, and a stronger sense of self as designer or maker.

Table 11: Pre-Post Responses to Why Students Consider Themselves to be a Maker or Designer – Examples of strongest gains

PRE		POST
• I'm not much of a maker because I don't really invent anything or I don't often have ideas that work out.	→	• I said maybe because I feel like I have the capability and potential to become a designer/maker in the future.
• I can see myself as a maker because I love to invent, come up with new ideas, and change the world. With so many great inventors today, in this day and age, anything can happen and anything can be invented. It just depends on you.	→	• Because I've realized that nowadays, there are not many women engineers or women video-game designers, so I would like to show the world that women are as smart, capable, or compassionate about technology as men are.
• I feel that way because creating something from scratch is not my type of job/career I want to do when I grow up.	→	• I think after seeing the potential of what makers can do I'm more interested in this subject.
• Because I work with other people I don't know if I can call myself a maker just yet	→	• I believed that as I am a part of FIRST robotics and that has given me the tools ability and opportunity to try being a maker and designer
• I chose 'Maybe' because sometimes, in Art, I create new designs, and in Science I've built a mousetrap car, which ran for about 12.2 meters; so I'm not sure if it follows in the designer/maker category.	→	• I see myself as a maker because I made a cookie cutter with the 3D printer, and now I am doing the social entrepreneurship project.

Students' confidence in design-related activities. Sense of identity often goes hand-in-hand with a sense of confidence and self-efficacy. At the post and follow-up surveys, we asked students to share how confident they were overall in relation to several design-related activities. Students responded on a 5-point scale that included a neutral midpoint. Over half (54%) responded positively, and the average for the full sample was significantly higher than the neutral midpoint (mean= 3.6, sd=0.90; $t(470)=13.831$, $p<0.001$). Moreover, among the 43 students who completed both the post and follow-up surveys, there was a statistically significant increase in overall confidence, $t(42) = 2.015$, $p=0.025$.

As with the question about identity, we also probed students' confidence with an open-ended question. On the post survey, students who responded positively to the item about their confidence were invited to briefly elaborate on their choice. Two hundred forty-five students provided elaborations, and of these 186 reflected valuable reflections. Nearly a quarter (23%) of students cited an increase in skills as having contributed to their confidence. Examples included, "In the Learning Studio project I learned how to create 3D models on Tinkercad which allowed me to use the printer very effectively and the Sprout computer made it very easy to work with presentations" and "I started to learn these skills by using the 3D printer and the Sprout. Before, I didn't know what to do but, now i do." A second trend was the connection between opportunities to practice, and increased confidence (20%). Students' responses evidencing these two themes included, "I acquired lots of experience working in situations like these"; "I feel more confident with 3D modeling now that I've been practicing;" "Since we have worked on projects like this in here, I am more comfortable using these skills;" "I got more comfortable with those things the more I used and applied them."

A third and related theme was exposure to the Learning Studio equipment and experience itself (12%). "Because I got to test things and try different methods and listen to others' ideas. I was exposed to more things than I think I would have been, and it has given me a chance to improve in these areas;" "I was able to explore with a different technology/equipment, that is more hands on, which gives you a different perspective to look at when solving a problem, or just doing everyday tasks." and "I hadn't done projects like we've done in here before so it's helped me learn how to do them and work with others on it."

Teamwork, learning from peers, and becoming more comfortable expressing themselves were also cited by students as reasons for why their confidence grew in the Learning Studio. "...before being in this class I didn't know how to really express my ideas and this class has made me try try to become a better inventor ..." "Since you work with other students you get a chance to open your social skills and when I teach things to other students it's easier for me to understand and remember what I previously learned." "...before I didn't like working with people. Now I work with kids that aren't my friends." "Before I got to the Learning Studio, I would keep my ideas to myself...now that I've gone through the Learning Studio I share my ideas." "We often work in groups to solve programming problems. Everyone usually has a different solution unless the problem is dead simple, so I became comfortable abandoning my ideas in favor of others."

Several students also described shifts in attitude toward taking risks, being more open with others, and feeling more accepted by peers through their Learning Studio experience. Examples of students' responses included, "I learned how to be more open with people and technology." "Before I was worried about breaking the Sprout and 3D printer. Now that I know how to use it, I'm not scared of breaking them at all" "... before if I couldn't do something I'd give up especially with computers but now I'd at least try and fix it". Interviews with teachers corroborated this theme. One high school teacher shared, "Tinkercad was new for me. When we were starting the prototyping and designing the cookie cutter, some of the girls were saying, 'I hate computers, I can't do this'! I told them, I'm in the same boat. I didn't know it either. And those same girls are now designing a special cookie cutter using Tinkercad for a special parent night at the school. It's just amazing to see them progress even though they had these preconceived notions that they can't do something or aren't good at it. (...) Now my students are not as afraid to try something new, and if it doesn't work we'll go back and take a look... It's nice to see them break away from the stereotypes that they can't do something, and get out of that fixed mindset of 'they've never been a computer person'".

3.4 Focal Outcomes

3.4.1 Engagement & Persistence

- Students are excited about coming to school
- Students are eager to visit the Learning Studio
- A diverse range of students demonstrates their enthusiasm for the Learning Studio
- Students apply skills and perspectives from the Learning Studio to other aspects of life both in and out of school
- Students seek deeper understanding and knowledge beyond the minimum requirements.

Figure 17: Engagement and Persistence Indicators

The first focal outcome for the Learning Studios was impacting student engagement and persistence. At the outset of the program, we identified several indicators to serve as operational definitions for these program impacts, as shown in Figure 17. We then gathered data from multiple sources to explore the extent to which the Learning Studio exhibited these indicators.

Analyses from the surveys, as well as conversations with teachers and students provided evidence that engagement and persistence had been positively impacted through Learning Studio participation. From students' responses to questions on the post survey, we learned that the majority of students endorsed frequently taking actions associated with engagement and persistence, such as continuing to work on an assignment beyond what was required ("keep working"), sticking with a tough problem until they solved it ("stuck tough"), and getting curious about how something worked ("get curious"). Figure 18 shows the distribution of students' choices across the response options for each indicator. On four of the five indicators, approximately three in four (74%-80%) students responded in the frequent zone of the scale, from a few times to many times. On each of those four indicators, approximately half (from 48%-51%) the students responded with "several" or "many" times.

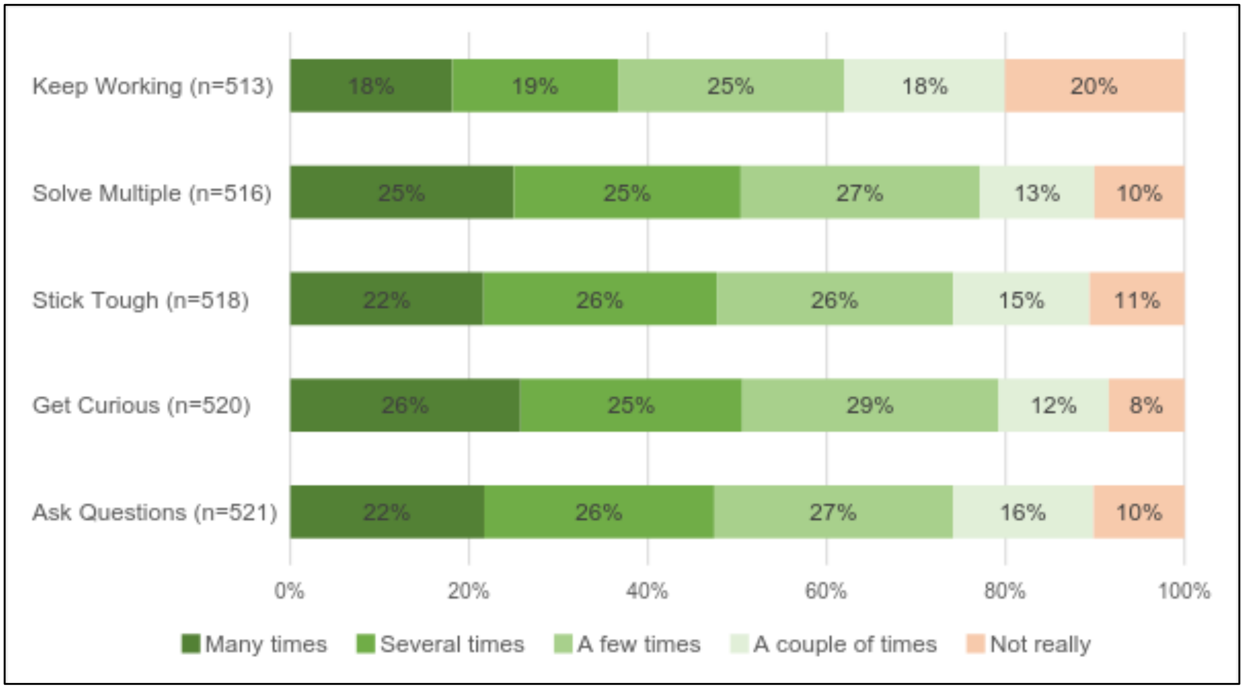


Figure 18: Frequency of Student Behaviors Related to Engagement and Persistence in the Learning Studio

We found further evidence of impacts on students' engagement and persistence in the open-ended responses they and their teachers provided on the post surveys. When asked to describe the ways they had grown in the Learning Studio, 6% of all students who completed the post survey cited aspects of persistence. Examples drawn from their responses include:

- "That you can be creative if you tried really hard but you had to put all the effort you have;"
- "Things might be hard sometimes you have to take a break from it but don't give up;"
- "Patience, it can get frustrating trying to figure things out but once you stay with it, it gets easier. It is just hard in the beginning when you don't have the confidence or experience to get where you want to be."

Teachers echoed similar observations when asked to share the specific ways that students had demonstrated engagement in the Learning Studio. Their post-survey responses reflected several of the indicators that had been independently set as operational definitions, including spending more time than was required in the Learning Studio, using time outside of class to work on their projects, and demonstrating unusually high levels of focus. Figure 19 presents a selection of their words.

- "Persisting through problems with their designs, finding humor while working through problems, managing impulses while collaborating, inquiring about other ways to accomplish tasks."
- "That sometimes learning is messy. Not all the time do our designs work on the first print. They also learned that it takes patience in order to persevere."
- "Students stayed focused and interested during the entire time while in the Learning Studio."
- "As a few of the students worked with the Sprout, they were reluctant to leave when the class ended. They also show focus on a level that I don't usually see."
- "They were excited to come to science and use the equipment. They also went home and talked to their parents about what they were doing. They were into the class from the moment it started."
- "They attend classes regularly on a voluntary basis, bringing with them more and more friends Spend hours at home preparing material for the next lesson (e.g. drawing backgrounds and characters for stop-and-motion)"
- "Students choosing to spend their free time in the Learning Studio was huge and showed true, authentic engagement."
- "High school students vote with their feet...if the release bell rings and nobody moves (instead my space starts filling up) you have authentic engagement in learning."
- "Many of the students involved in the Learning Studio continued their work in the classroom and at lunchtimes in the Learning Studio. There was also a large uptake of students using Tinkercad at home."

Figure 19: Teachers' Examples of Student Engagement and Persistence in the Learning Studio

In interviews as well, teachers noted several ways they had observed students' engagement and persistence develop in the Learning Studio, and shared examples of those mindsets translating to other classes and subjects. "I've seen that maker mindset grow over the year and it's really powerful because it translates into math, and it translates into reading. It's not just limited to the making that we're doing. When they come across a problem that's hard in math they understand that, ok, it is hard, but it's a challenge that I'm not good at yet. I can improve, I have to work, I have to practice...they embrace challenges a lot better than they had if they hadn't had [the Learning Studio]. The whole saying-something-is-too-hard-and-giving-up doesn't really apply to them too much."

A high school teacher described a benefit of the Learning Studio as helping, "to remove the fear of the creative. Because schools have this tendency to take away imagination. Everything is black and white. They worry about perfection, but that's not how the real-world works. So [student] lose their creativity, they lose their problem-solving skills. They lose the imagination and are afraid of entering the 'what ifs' scenarios, the 'how might we' questions, because they focus more on themselves than on others. So it helped to develop collaboration and communication skills as they are teaching each other how to do things. It helped them learn to take some risks, particularly when it's computer based and it doesn't work out. You erase it, you delete it. That's not a big deal. The only question I would ever ask is, 'what did you learn from it'? So they learn to get comfortable being uncomfortable, and they learn to analyze their failures, not just quit but to persevere through them, and through iteration learn to improve."

A number of teachers commented that student growth in the Learning Studio had ripple effects into other classes and domains. "Last year I did Maker Mondays, so every Monday there was an hour dedicated to Making. This year I just kind of embedded it throughout. This is my second year, and my first year with the Learning Studio and that cool technology. [The students] go to science once a week and the science teacher has been doing a lot of STEM activities and challenges and she said that she can totally see a difference in the kids in my class this year, and even the kids I had last year, when they encounter some of those STEM challenges or any kind of making or problem solving, that they handle it a lot better, they persevere, they don't give up, they come up with some really creative ideas and they feel confident about them. You can see a difference and that really inspires me to keep going."

Finally, on the follow-up survey, we asked teachers to indicate on a 5-point response scale, from strongly disagree to strongly agree, whether they felt students had put in more time than was required, and had found personal meaning in their Learning Studio projects. The response scale included a neutral mid-point. Among the 27 teachers who completed the follow-up survey, the great majority (85%) agreed that students had invested more time than required, and nine in ten teachers (89%) agreed that the projects had personal meaning for students, with 44% strongly agreeing. In addition, the average responses on these two items were also significantly above the neutral mid-point of the scale, $t(26)=6.596$, $p<.001$; $t(26)=10.198$, $p<.001$, respectively.

3.4.2 Agency & Ownership of Learning

- setting personal learning goals
- seeking and responding to feedback
- taking intellectual risks
- personalizing projects or assignments

Figure 20: Agency and Ownership of Learning Indicators

The second focal outcome we anticipated observing in students was an increase in their agency and ownership of learning in the Learning Studio. As with engagement and persistence, at the outset of the program we crafted a set of indicators, listed in Figure 20, that could serve as operational definitions for this outcome. From analyses of the surveys and interviews, overall we found support that the Learning Studios promoted this aspect of a maker mindset.

Affording students opportunities to exhibit personal agency and ownership of their learning is not common in traditional classrooms for a variety of reasons. One aspiration of the Learning Studios program was to contribute to a culture of learning in which students take action to drive their own growth. This translated to anticipated changes for teachers as well as for students. At the follow-up survey, teachers expressed nearly unanimous (96%) agreement that through their participation in the Learning Studio, they are now more comfortable leading projects in which students have a high degree of agency.

To capture the point of view of students on these outcomes, we included five specific actions related to agency on the post survey and asked for ratings of how often they engaged in them during their time in the Learning Studio. As shown in Figure 21, across all five indicators, approximately two-thirds of students reported carrying out the target behaviors from a few times to many times, with over 40% reporting these behaviors several to many times. Moreover, the vast majority (84%-86%) enacted them to some extent.

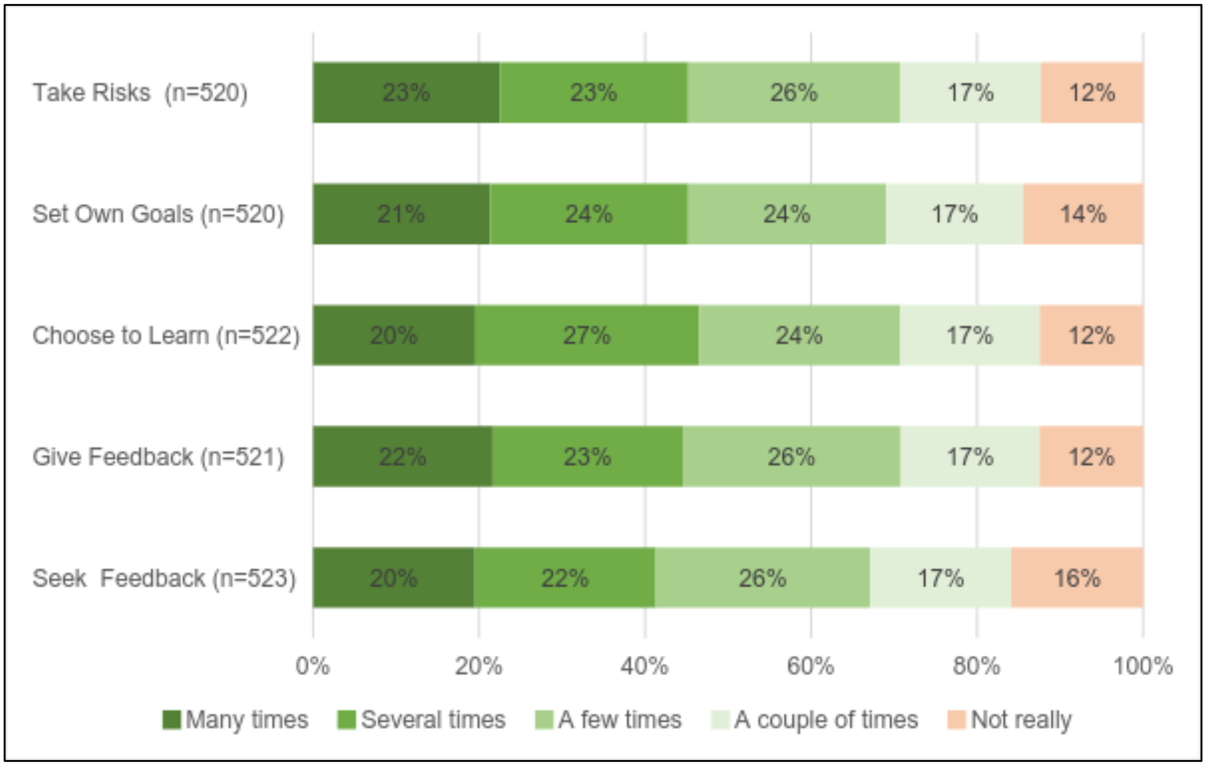


Figure 21: Frequency of Student Behaviors Related to Agency and Initiative in the Learning Studio

To further probe the extent to which students gained facility in seeking, providing and responding to feedback, we posed additional questions to that effect on the teacher follow-up survey. The great majority of teachers, responding on a 5-point scale that included a neutral mid-point, felt that their students had grown in their active use of feedback on their work. These data are presented in Figure 22.

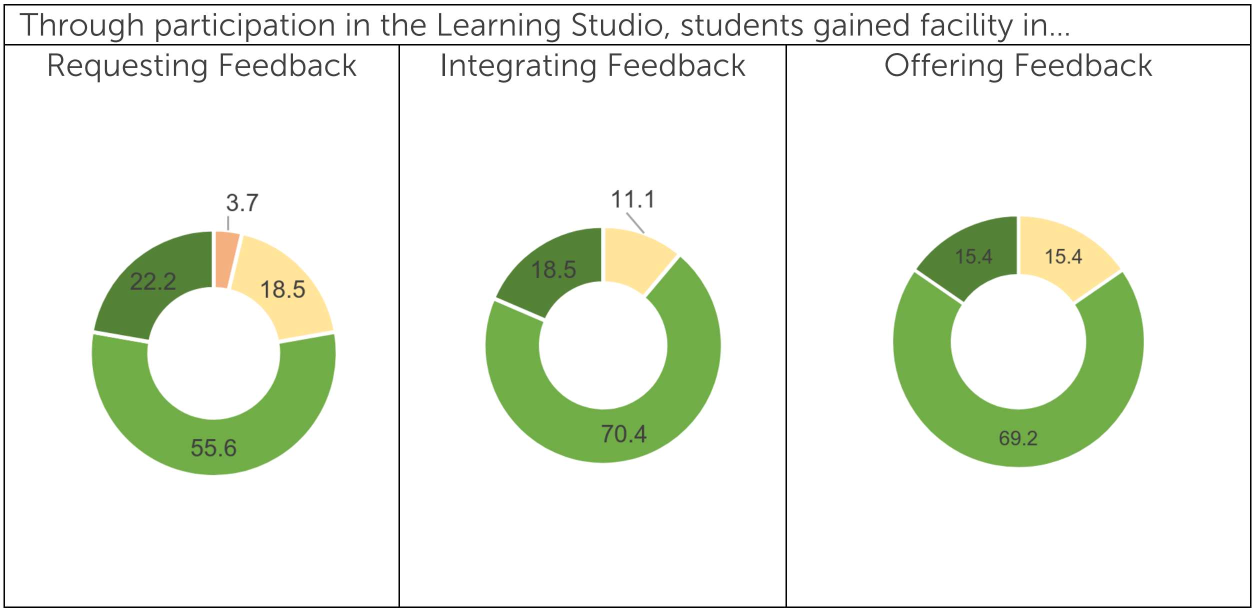


Figure 22. Teacher Ratings of Growth in Students' Feedback-Related Indicators of Agency

Evidence of growth in students' initiative in the Learning Studio also surfaced frequently in interviews with teachers over the course of the program. One high-school teacher shared, "Earlier on, they would come in looking for the one correct answer. 'Is this right'? And I'd tell them, 'I don't know -- You're asking me if it's right, you haven't even told me what the question is. How did you come to this answer? What evidence do you have to support this answer? Your answer may be right, try it'." The students initially are 'horrified'. "Then they start realizing that I am teaching the way it works in real life, and that if you work for me, you come to me with solutions, now you're valuable. That's something that they struggle with." By the end of the year, "they don't really have problems with it anymore. They get used to it and it helps them in their core classes also. (…) The design-based system gets them to take responsibility and accountability and ownership of what they're working on."

A middle school teacher explained, "It's really student guided, led and directed. We're finding out that the engagement is increasing and they are starting to understand that if they don't know how to do something they go to the Sprout and see if they can figure it out there. (…) Students are also managing their risk as they work. They say, well if we do this are we going to lose time? There's an increase in planning and managing impulsivity. Most of that learning came from the Parts, Purposes and Complexities project [that Digital Promise Global provided, based on the thinking routine created by Agency by Design]. They got to choose what they wanted to take apart. Rather than ripping things apart, they first sat down, thought about how it was put together, took pictures, identified which tools they would need first. Whereas in the past they'd have a hammer out right away just to deconstruct something. (…)

There's also been an increase in inquiry - students wondering about things, asking a question then going in a direction to find their answers."

This theme was echoed by others. For instance, a high school teacher found that with students' increased comfort came increased independence. "Early on in this process, more often than not I was focused on the tech and the process, guiding them in the correct steps through their process and reassuring them that it was okay to fail. And my role has shifted recently to more of someone they can bounce ideas off of, and talk more about their ideas and more about process." And another highlighted the importance of providing students with options to set their own learning goals. "I continue to praise the open-endedness of this process and of the Learning Studios. I have students that are learning about topics that are never going to be covered in a standard but they are important to them and they are learning about problems that are going on around the planet and country....they are able to stand up and speak very intelligently about their topic. It's empowering to them and certainly motivating for me."

The principal of an elementary school explained, "The main area of growth that I witnessed was in the children's ability to think outside the box, once they got the idea that they were *allowed* to think outside the box. The children are so used to being rooted in fairly traditional pedagogy. So when you suddenly say, 'we're going to do Learning Studio and you're going to work in groups and come up with solutions to these challenges... That's a big, big change from the teacher standing in front of the group directing the activities."

3.4.3 Empathy, Collaboration & Communication

- Awareness of the importance of taking perspective and understanding where others are coming from
- Ability to communicate effectively in a group work environment
- Ability to work effectively in a team, such as recognizing strengths that others bring, compromising and working through disagreements

Figure 23: Indicators of Empathy, Collaboration & Communication

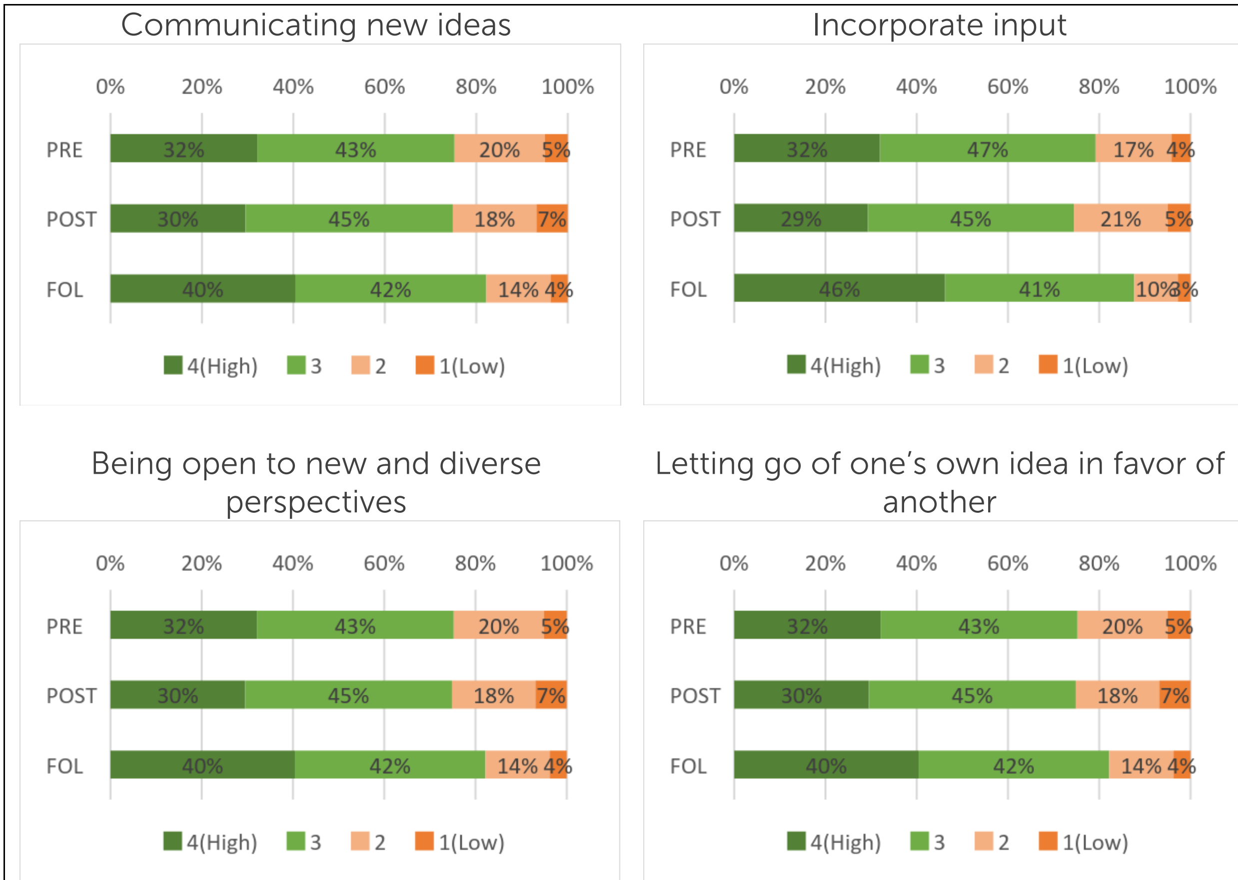
Design thinking and making do not take place in a vacuum. The ability to communicate one's ideas, recognize others' strengths, navigate disagreements, and understand where others are coming from are all critical competencies. The third focal outcome for the Learning Studio targeted these abilities for communication, collaboration and empathy, defined in operational terms using the behaviors in Figure 23. Overall, we found support for Learning Studio contributions to students' growth in their collaboration and communication abilities among a subset of students. Whereas ceiling effects on survey items limited insights about impacts in this area, open-ended responses from students and teachers on surveys and in conversations generated many anecdotes of growth, especially for teamwork and collaboration.

Both teachers and students responded to survey items regarding various aspects of collaboration and communication. Specifically, we asked them to rate their personal comfort levels, on a 5-point scale from "Not at all comfortable" to "Totally Comfortable" for: communicating new ideas to others; being open to new and diverse perspectives; incorporating group input and feedback into work; and letting go of your idea in favor of an idea more supported by members of your team. In addition to rating their personal comfort, teachers were also asked to indicate their comfort facilitating students in these areas.

From students' pre to post surveys, we found marginally significant gains on being open to new and diverse perspectives; however, responses for the other communication and collaboration indicators remained fairly constant over time. Among the small group of students who completed all three surveys, results were mixed as well, with significant changes found only for "letting go of your idea in favor of an idea more supported by members of your team". Appendix D presents these results in detail.

Since these response trends did not reflect findings from interviews and open-ended responses, we took a closer look at the distributions across the full set of responses at each timepoint. This revealed what is known as a "ceiling effect" in the student data. As can be seen in Figure 24, at the outset of the project, fewer than one in five students reported low comfort levels for the indicators. In other words, with approximately 80% of students already expressing their comfort on in these areas, there was little room for improvement. Notwithstanding, for all four indicators, the percentages of students in the "low comfort" zone were lowest at the follow-up survey.

To get a better understanding of the extent of growth for these outcomes, we filtered for students who reported attending the Learning Studio at least 10 times. For these four items, we calculated the number of students who moved to higher comfort levels from pre to post. For students whose pre-survey responses were '3' or lower, 37% showed growth for communicating new ideas to others; 36% for incorporating input; 51% for being open to new perspectives; and 30% for letting go of one's own idea in favor of someone else's.



+*Data shown represent the full set of responses at each survey*

Figure 24: Distributions of Student Responses for Communication and Collaboration Indicators+

Teachers' responses to the same questions followed a different pattern, but also evidenced a ceiling effect. From pre to post, teachers reported personal growth on two of the four indicators: communicating new ideas to others, $t(19)=2.517$, $p=0.01$, and incorporating group input and feedback into work $t(19)= 1.831$, $p=0.041$. On average, teachers' comfort communicating new ideas to others was also higher at the follow-up than at the pre-survey. Examination of the distribution of responses to the questions showed that from the outset, teachers were highly confident in their ability to facilitate students in these areas. Of the 27 teachers who responded, only one expressed low comfort at any of the time points for each indicator. Moreover, at the pre-survey, between 60% and 85% indicated high levels of comfort.

Because of the observed ceiling effects on these items for students and teachers, we focused our interpretation on related questions from the post and follow-up surveys, as well as on open-ended survey responses and interview data. These analyses yielded substantial evidence that the Learning Studio had positively contributed to students' growth in communication and collaboration. On the follow-up survey, we asked teachers to share their perspective on whether students had improved their collaboration and communication abilities through their participation in the Learning Studio. Of the 27 teachers who responded, virtually all agreed that their students became better collaborators, with nearly two-thirds (63%) strongly agreeing. All but one teacher agreed that their students had improved in their ability to communicate their ideas to others, with over half (55%) strongly agreeing with the statement.

A second source of quantitative data on these outcomes were students' ratings of six indicators used to measure students' community and social support behaviors during their time in the Learning Studio. Students reported frequently incorporating ideas from their peers into their own work, helping peers to brainstorm, providing support to a peer, and encouraging a peer, as shown in Figure 25. Well over half also reported working with someone new.

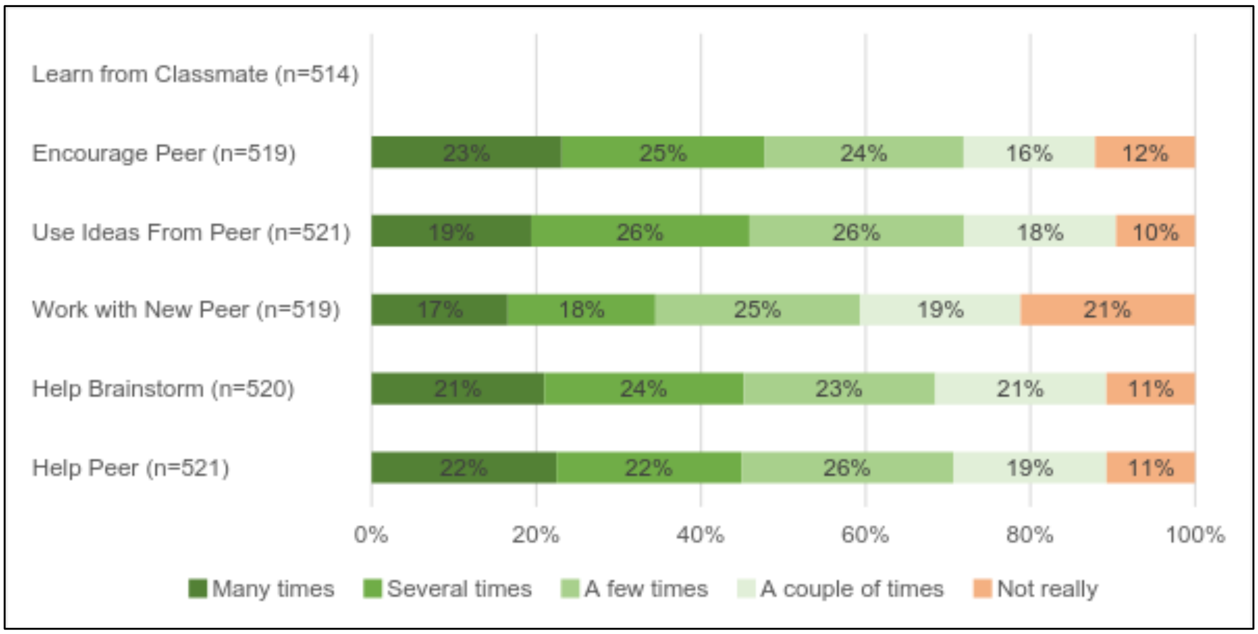


Figure 25: Frequency of Student Behaviors Related to Community and Social Support in the Learning Studio

- *I learned how to work with people that I may not like or may not like me and how to be more accepting of other people/teammates ideas or observations.*
- *I learned that teamwork is an important part of using the Learning Studio.*
- *I learned how to work with others and be more open minded to different ideas.*
- *That working on a project together instead of separate is more effective.*
- *You need to respect each of your team members' ideas.*
- *I learned that being in a group can be hard to work with because sometimes YOU want to take charge on the project and group but sometimes you have to listen to others and see what their ideas are, and that there is a lot i can do with a 3D printer to change the world.*
- *I learned to always keep an open mind, to not shoot down ideas that haven't at least been tested. Cooperation is almost always a key to being successful.*

Figure 26: Examples of Collaboration from Students' Open-ended Survey Responses

We found further evidence of students' improved collaboration skills in their open-ended survey questions. Fourteen percent of students, when asked what they had learned in the Learning Studio, cited collaboration and teamwork as an area of growth. Examples of their responses appear in Figure 26 and reflect perspective-taking, openness to new ideas, and the value of working collaboratively.

Interviews with teachers also yielded many examples of student growth related to communication and collaboration. A high-school teacher commented, "They have gotten better and better at listening to one another. Just being in a position where they are being asked to collaborate constantly, where they are being assessed by their peers on that collaboration -- something I've put in place this year. They have to really lean on each other." The principal of a traditional elementary school reflected, "We found that one of the road blocks early on was their lack of collaborative skills. What we've seen over the course of this last term is the improvement there. Generally, when we started, we were doing basic STEM challenges and some kids had literally no idea how to work as a group. Teachers have noticed that there has been significant growth in a number of children who started out quite anti-group work and have realized that you have to work with a group to be successful."

Regarding communication skills, another elementary school teacher shared, "The group work is so much stronger because each of the kids is advocating for their thought process...They have to think about things from different angles, and they have to think about what do other people value and so their communication skills are building because they can't just come from their perspective." The teacher also described how students have learned to value the contributions of their peers. "I brought 20 kids to present in [city] this year and in preparing the kids for questions, I was able to hear from them what they felt was important. One of the things that I liked the most was the kids talking about how much they learn from each other."

One high-school teacher described the difference between group-work in typical classrooms, and collaboration in the Learning Studio. "A lot of teachers will assign what they call 'group work' and group work doesn't work. One person does everything, or one person is insistent that it has to be done their way. I don't do that. I tell them, you have to figure out what each other's strengths are and utilize those strengths. So one person is going to design, one person is going to research, one person is going to build. But while you're doing that, if you're primarily responsible for the building, you still have to know the research and the design...and you see them come together...and all of the sudden, you'll find the builder becomes the better designer, the designer becomes the better researcher, the researcher is becoming the better builder."

Teachers also described students reaching out to each other for help and input. "The kids are talking to other kids who have used [the technology]. Other kids are saying 'yeah, we did this but that didn't work out so well, I'd recommend doing it like this..." I find myself asking the kids, too. 'Has anyone ever done this before?' and usually there's someone in the group who will say, 'Yeah we did that but it didn't work because of this'...and that's the more important part: being able to articulate why you think something is, not just, I don't like it or I like it."

3.4.4 Design Thinking & Problem Solving

- Recognizing that the material world is designed;
- Ability to identify problems to solve;
- Ability to take perspective on one's own creation and those of others;
- Demonstrating variation of efforts; and,
- Ability to recognize failure and iteration as a regular part of the design process.

Figure 27: Indicators of Design Thinking and Problem Solving

The fourth and final focal outcome we anticipated for participants in the Learning Studio was growth in design thinking and problem-solving abilities. Key markers, which served as operational definitions, appear in Figure 27. Overall, we found some positive impacts on students' beliefs and attitudes in this area; however, evidence of growth in students' awareness of and facility in design-based processes was mixed. On the one hand, quantitative responses from students and teachers regarding design-related activities showed increases, and interviews with teachers offered some examples of students engaging in design processes. At the same time, few differences were found from pre to post when students were asked to describe a designer or maker in their own words. Moreover, the great majority of students' solutions to three distinct design-thinking prompts did not demonstrate a grasp of key characteristics of the design process, such as developing an understanding of the problem space, developing prototypes, testing and iterating the design. In this section, we lead with the quantitative data, and transition to the qualitative sources of data from surveys and interviews to explore impacts on design thinking and problem solving.

Quantitative Findings. As with the other focal outcomes, we posed questions to teachers and students about their comfort levels with processes related to design thinking and problem solving. Teachers were also invited to indicate their comfort facilitating their students in these design processes. Results for students' responses are presented in Table 12. From pre to post, main effects were significant for one of these indicators, though the average at post was still below the threshold for "comfortable". Moreover, students' reported comfort taking something apart dropped significantly from pre to post survey. When these questions were posed again in the follow-up survey, trends for most items were generally positive from pre to follow-up but tended to be relatively lower at the post survey. The repeated measures analysis detected at least marginally significant differences for three items across all three time points.

Table 12: Students' Comfort with Design Thinking and Problem-Solving Activities++

	PRE		POST		FOL			
	Mean	sd	Mean	sd	Mean	sd	PRE-POST	PRE-POST-FOL
Defining problems to investigate	2.81	.795	2.88	.814			*t*(304)=1.310 (ns)	
	3.03	.707	3.18	.683	3.31	.694		*F*(2,76)=2.634^{+}
Taking something apart to see how it works	3.22	.847	3.06	.869			*t*(304)=-2.936**	
	3.03	.915	2.95	.837	3.13	.906		*F*(2,74)=.590 (ns)
Assembling something WITH instructions	3.47	.753	3.48	.744			*t*(303)=.205 (ns)	
	3.55	.602	3.45	.602	3.71	.515		*F*(2,74)=2.552^{+}
Assembling something WITHOUT instructions	2.49	.992	2.63	.986			*t*(303)=2.791**	
	2.26	.891	2.61	.916	2.95	.899		*F*(2,74)=12.448***
Working effectively when process is ambiguous	2.74	.821	2.77	.865			*t*(304)=.686 (ns)	
	3.05	.695	3.03	.753	3.16	.916		*F*(2,74)=.471 (ns)

$^{++}$Response scale: 1 (Low) - 4 (High)
$^{***}p<.001$; $^{**}p<.01$; $^{+}p<.10$

For teachers' personal comfort with these design-related processes, a clear ceiling effect was detected. Nine in ten teachers reported moderate to high comfort on the second and fifth indicators; 73% to 79% reported positive comfort levels on the other three indicators. Because of the high response levels at the pre-survey, there was little room for additional growth during the Learning Studio implementation. However, some increases were found to be statistically significant from pre to post. For instance, teachers reported increased comfort in defining problems to investigate, $t(19)=2.349$, $p=0.015$ and assembling something with instructions,

$t(19)=2.333$, $p=0.015$. Regarding teachers' comfort facilitating students in these activities, the only significant increase from pre to post was in assembling something using instructions, $t(14)=3.228$, $p=0.003$.

On the follow-up survey, we asked teachers two additional questions about this focal outcome. All but one teacher agreed that they were now more skilled at leading students in the design process, with 37% strongly agreeing; 93% of teachers agreed that students' perspective-taking ability had improved, with 44% strongly agreeing.

Qualitative Findings: Definitions. The pre and post surveys included several open-ended prompts to students to respond in their own words. One question asked students to describe a designer or maker in their own words. Each students' pre and post responses were compared for differences. Of the 401 students who provided a response at both time points, 61 were scored as having improved definitions in some way. Select examples are shown in Table 13. Among the improvements found from pre to post were references to problem solving, persistence, a maker mindset, and improving the world. Several students' responses suggested that they had not become familiar with the term designer or maker, and interpreted the term in the context of fashion or art.

Table 13: Examples of Students' Pre-Post Definitions of a Designer or Maker

PRE	POST	Improved?
Any person who is thriving and creative.	A designer is someone who solves a problem. No matter how big or small. They are innovative and prepared.	Yes
Someone who can take simple everyday things and create something new and abstract out of them. For example, wood is just wood unless you make it into a chair or a house.	A maker is someone who uses technology to create new things. They may improve on existing inventions or create solutions to new problems.	Yes
A person that have no limits from what they are making and creative freedom.	I see a designer as an very creative person to come up with design that help people in their everyday lives.	Yes
Creative.	A designer/maker is someone who is able to design and make something. They usually need some creativity and are able to reach goals.	Yes
I would describe them as very smart person who knows what they're doing with tools/computer, basically anything.	Someone who is intelligent and someone who is smart about their materiel making.	No
To me a designer is someone who comes up with a design for a product and a maker makes the actual product.	A designer is a person who designs a product and a maker is a person who makes the product.	No
I will describe them as inventor and someone with a huge imagination.	Someone very creative and one of the smartest groups of people	No

Qualitative Findings: Design Scenarios. To determine whether students had progressed on design thinking processes beyond self-report or their teachers' perceptions, the pre and post surveys for students included three design scenarios. In the first item, students were shown a fan and asked to describe how they would figure out how it works, using as much detail as possible. The second question showed a three-dimensional image of a 3D-modeled car and asked students how they would model the object in a program like Tinkercad. The third question described an everyday problem scenario: "When students at the Imaginary School go outside for recess, they have an area on the floor of the cafeteria where they leave their bags. As bags get thrown and piled on top of each other, students are finding that things inside them are getting broken." For this third scenario, students were asked to explain, in as much detail as possible, how they would go about developing a solution to this problem.

Analyses of students' responses to these questions suggest that the majority of students did not develop explicit knowledge of a method for design thinking. For the fan item, roughly one in five (22%) of students showed at least some improvement from pre to post, with just 2% showing strong improvement; 78% did not show evidence of growth. Examples of pre-post responses scored improvement as strong, moderate, or none are shown in Table 14.

Table 14: Examples of Students' Pre-Post Solutions to the Fan Scenario

PRE	POST	Improved?
The propellers show that they move quickly because they are in a cage so I assume that it will give of wind.	The first thing that I would do is try and see what the purpose of the machine is, then I would try and take apart the cage and see if the blades spin, and if they don't then I would take the battery out and try to see how that works.	Strong
The blades rotate which creates a breeze.	I would first examine the outside of the device, then I would take it apart and look at the insides and try to find out how they are connected and work together.	Strong
It works as a function, you press/put something into it. And then you get the results, in this case the fan blows out air.	I would take it apart, and try to put it back together. I would examine all the parts and see how they work together before actually trying to rebuild it.	Strong
Ask siri google to see how it works.	You press a button and it starts the engine and it makes the fan work.	Moderate
A switch would trigger the fan to start going by blowing air to cool.	Pull off the cover and then you pull the fan off and then you search the inside bit. Then put it together again.	Moderate
You can find a button, search on google or inspecting it in detail.	I would look inside and I can see a fan so it gives wind to you when it's hot. Its covered with metal bits around the fan and that is to not hurt you.	Moderate
I would take the object apart and look at the parts then try to piece them together to find out how the thing works.	I would take apart the fan and look at all the parts.	None
I would find the button.	I would find the plug in and turn on the on button.	None

The second scenario asked students how they would model the 3D car shown in an image. Overall, stronger outcomes were found for this question, which focused on technical aspects of designing and making. More than three in ten students demonstrated improved responses from pre to post, with 5% showing especially strong growth; for this performance task, 65% of students' responses did not demonstrate growth. Table 15 provides selections of responses.

Table 15: Examples of Students' Pre-Post Solutions to the 3D Modeling Scenario

PRE	POST	Improved?
How I would model the object above is to shape the car with different pieces to form the car shape.	I would model the picture in Tinkercad by getting two cylinders, a trapezoid, and a rectangle that has two holes due to the cylinders going through. Place the two cylinders near the edges of the rectangle so holes are created and put the trapezoid on top.	Strong
I do not know what Tinkercad is, but I hope I will get to learn what it is and how to use it.	I would start off with a rectangle and then use holes to shave off pieces of the rectangle and give it the shape of a car, i would use about two holes to give the car the shape on the roof of the car as depicted in the illustration, and another four circular holes to make space for four solid circles to replace the holes and act as wheels.	Strong
Use a trapezoid, a rectangle and 2 cylinders.	Grab two cylinders and place them horizontally, grab two arches and stretch them to the length of the cylinders, then I would grab a trapezoid and place it on top of a rectangle on the bottom in between of the arches.	Strong
I don't know yet.	Create that figure using the different objects the program gave us and all the options they let us use like grouping.	Moderate
I would learn more about it.	you bring the object to the work space and put them to the size that's asked.	Moderate
it is a car.	I would use shapes and group them.	Moderate
make a car out of cardboard and other stuff then scan it with the sprout.	Build it out of clay put it in the 3D printer and wait for it to print.	None
First I would find wheels for a substitution and use cardboard to create the body. Then I would colour or paint everything else.	I would first have to create a model then make it piece by piece. I would first make the body and then the wheels and a stick like object to connect the wheels.	None

The third scenario focused on problem-solving in a real-world situation that would have required developing an understanding of the context, interviewing key individuals such as students and administrators, and then developing, testing, and iterating a solution. Roughly 9% of students' responses evidenced some improvement from pre to post, with a handful of strong examples, as illustrated in Table 16. However, the majority (91%) showed no improvement.

Table 16: Examples of Students' Pre-Post Solutions to the 3D Modeling Scenario

PRE	POST	Improved?
I would tell the students to put their bags in the locker or put their valuables in their lockers.	I would determine what the problem is, which is that items are getting broken. I would then find out what has caused the problem. The items are breaking because students are piles bags on bags. I would then find a solution that would prevent things from breaking. The students can put their bags in their locker. They could also put their bags along the wall so that there isn't a pile.	Strong
Have separate areas for individual bags.	Find out what is causing the problem, then brainstorming solutions to the problem, eventually picking one that suits best and is the most efficient.	Strong
Place them neatly on the side.	I would use Tinkercad to create hooks for each student and use the 3D printer to obtain them so they kids can hang up their bags.	Strong
Try to make something out of it like a giant robot.	First I would look at the destroyed objects inside the bags. Next, I would think on how to fix it. Finally, I put the idea to work.	Moderate
I'd make cubby with everybody's names on them that are big enough to fit their bags and when the go out they are in number order so the each put their bags in their cubbies and go out.	I would make a cubby design on Tinkercad then print it out as a prototype. Then I would gather wood and build cubbies and engrave each of their names on their cubby then they would each have a cubby. Or if buy lockers.	Moderate
I don't KNOW...maybe modifying the bags so they can protect the content they carry more effectively???	Testing materials that would hypothetically keep stuff from breaking and modeling redesigns for either the floor or backpacks that would prevent future breakage.	Moderate
You might solve this problem by creating assigned cubbies so things are not broken when slapped against each other in book bags.	A solution might be that there are cubbies made and each student is given a number and that student has to put all of their things unneeded for recess in that cubby.	None
Use shelves.	Build a shelf.	None

Qualitative Findings: Teacher Interviews. Conversations with teachers about students' design thinking offered additional insights. From these teachers, we heard examples of several indicators for this outcome. For instance, some teachers described an increase in recognizing that the material world is designed. One teacher reflected, "You just start to see that they see the world a little differently and now when they have an idea, they're like, 'I can make that' and that's kind of cool."

We also found that in classes where a design process was already present—for instance, for students following a Project Lead the Way curriculum, the technology enabled them to focus more on the design process and iterations. "The equipment itself, like the Sprout, has prompted a different skill set, just working in that virtual 3rd dimension. Or being able to look at a project from different sides. Manipulating those programs for the 3D printing has given them access to new skills, or to try new things”. An elementary teacher explained how the touch screen enabled her youngest students to interact effectively with the design software—something that was not possible when reliant on a mouse. From a design point of view, access to the Sprout and 3D printer meant students could focus their attention on the design process, iterating more quickly than if they were working exclusively with physical materials. Teachers described the technology as an asset for creativity and innovation. “Giving them new tools is giving them the realization that they have the capacity to go out and learn. They never would have dreamed they’d be 3D printing or be able to design something that could be printed on a 3D printer.”

One high school teacher attributed an increase in the complexity of student work to access to the technology. “Some students are working on NASA project, where they are asked to design the spacecraft that is going to take a man to Mars. They’ve been designing it in Tinkercad and I've been working with them to get that printed. What they've been able to accomplish and their attention to detail is rather staggering. ”

3.5 Students who Struggle

In schools around the world, many students struggle in a variety of ways, and for a variety of reasons, to succeed academically. For some, the format of traditional classrooms fails to capture their interest and energy. Others face learning disabilities related to cognitive processing or attention. Because the Learning Studio program aimed to foster an interactive, collaborative learning environment that differs from typical classrooms, we anticipated that students who struggle at school might find new opportunities to engage and experience success. We explored this expectation through closed- and open-ended survey questions as well as in interviews with teachers. By teachers’ estimates, well over 300 students with documented learning disabilities were served by the Learning Studios program. Overall, we found good support that the Learning Studios provided opportunities for students who struggle to discover new interests, to develop valued expertise, to grow in their confidence, and to build positive rapport with their classmates.

Learning Studio Benefits. A first indicator of this area of impact was teachers’ strong endorsement on the follow-up survey with the statement that some students who are not typically engaged in classes really got into the Learning Studio projects. Nine in ten teachers agreed, with 41% strongly agreeing. The post survey asked teachers to elaborate on the Learning Studio experience of students with diagnosed learning disabilities (LDD), and interview questions also probed teachers’ observations in this area.

A strong theme that emerged from teachers’ written responses, as well as in conversations, was the opportunity for LDD students to develop expertise that gave them confidence as well as new status among their peers. As one teacher wrote, “Some of the students with learning difficulties found ways to express themselves and assist their groups in non-traditional ways.” In interviews, another teacher described a student who struggled with reading and low self-esteem. "She was so proud that she got hers done and understood it. You could just see her eyes light up and her confidence build. And then she could share and help others." This observation was echoed by another elementary school teacher, who remarked, "The kids are not all good at the same things, but if you find those kids who are 3D experts, now they have something they feel they can contribute to the whole. It's adding those options and areas for kids to find their expertise."

At one elementary school site, teachers and students were especially struck by the unexpected emergence of an autistic student as the school expert. "It was new for him to be such a help -- for him and for everyone else. That opened up a lot of eyes in the class. The student told me it was the best thing he's ever done in school. 'Because I'm helping everybody. I feel really good because I'm good at it.' This theme, of students seeing themselves, and being seen, in a different light through the Learning Studio experience was found across grade levels. A high-school teacher explained, "You may not do well in a traditional classroom, where you feel like there's a right or wrong answer and it becomes easy to be discouraged if you always get the wrong answer. Take [student], for example. She tries really hard, but she's also very susceptible to saying, 'I don't get it, I don't belong here'. For the hour of code, I asked them to come up with a way to do code a button that looked like a lion and played a lion sound. There are a lot of ways you can do that, so it provides an opportunity. She came up with a different way of doing it that was right. That moment where she gets to see that she came up with something that the teacher didn't come up with."

We also found some evidence that the confidence LDD students gained in the Learning Studio flowed over into their other classes. For example, a high school teacher recounted, "They're used to being told 'you don't get it' repeatedly. And I would just ask questions, 'you know how to use the apps on your phone? How'd you learn those? Find what you like that you're curious about and explore it.' Well, they found that they enjoyed it. That really boosted their confidence and their problem-solving skills, their communication skills, and as a result, the reports I get back from their other classes is that they started doing better and framing things differently there."

Challenges to Engaging Students Who Struggle. From open-ended survey responses and interviews with the focal site teachers, we concluded that for the most part, teachers did not experience insurmountable challenges specifically related to working with LDD students in the Learning Studio. Of the twenty teachers who responded to this question on the post survey, half indicated that no unique challenges had been encountered. Among the ten who did describe challenges, the responses were varied. Common themes included the need for extra time and additional support. "Initially, these students found it difficult to add value to their group as social and emotional barriers prevented them from really being part of the group. However, as their ICT skills developed, they became known as the group's go to person for help with Tinkercad or Powerpoint which in turn provided them with more respect from their peers and a higher level of confidence." Another teacher wrote, "They just needed a little additional time and support. Many times they were worried about doing it 'wrong' but once they figured out they could do it whatever way was best for them, they excelled."

3.6 Student Outcomes Associated with Implementation Characteristics

As described in Section 1.2, what the Learning Studio program had in common across all sites was the provision of an advanced technology package for designing and making, access to an online professional learning community, and a set of project guides and Challenge projects which teachers could choose to implement at their discretion. This resulted in marked variation across sites in terms of which projects were carried out, the ways in which Learning Studio activities were integrated into students' broader curriculum, and the nature of the guidance and instruction students experienced. Another factor distinguishing each site was the unique background each teacher brought to their respective Learning Studio implementation. To explore whether these variations in Learning Studio implementation sites were associated with differences in student outcomes, we carried out two sets of analyses. The first focused on project implementations; the second examined the effects associated with teacher background and experience.

Teachers' Use of Project Guides and Challenges. We first looked at student outcomes in relation to the number of projects their teachers used in the Learning Studio during the first phase of implementation, through December 2016. In this context, "projects" refers specifically to the project guides that the Learning Studio program staff developed and offered to teachers. Examples of the project guides appear in Appendix A. In addition to the culminating Challenge project, a total of ten project guides were available to teachers. Four of these were suggested for "project of the week" in a sequence. To calculate the number of projects completed, we linked teachers' responses about implementation to student data. We then examined correlations between the number of projects each student completed with their focal outcomes. To provide context for this analysis, Figure 28 presents the distribution of teachers' responses to the number of Learning Studio projects they completed with their students.

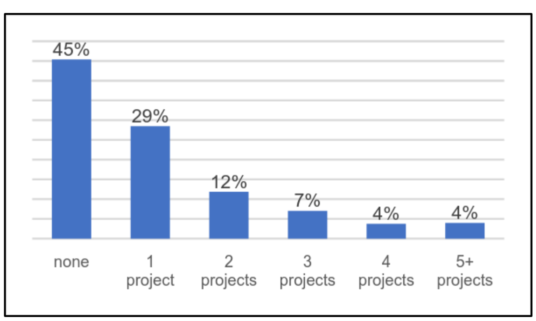


Figure 28: Number of Learning Studio Projects Implemented, by Teacher

Results suggest that for three of the four focal areas, the more Digital Promise provided project guides a teacher implemented with students, the stronger their students' outcomes were (See Table 18). For engagement and persistence indicators, every indicator had positive and significant correlations, ranging from *r*=0.103 to 0.145. Similarly, all indicators related to agency and ownership of learning were at least marginally significant. The highest correlations were found in this category, with choosing to learn something new and giving feedback to peers showing the strongest relationships with project exposure. All but one of the collaboration indicators reached at least marginal statistical significance, as shown in Table 17.

Table 17: Correlations Between Learning Studio Project Exposure and Focal Outcomes

Engagement & Persistence n=394 to 398		Agency & Ownership of Learning n=368 to 399		Collaboration n=397 to 399	
Kept Working	0.117^{*}	Took Risks	0.097^{*}	Encouraged Peer	0.123^{**}
Solve Multiple	0.122^{**}	Set Own Goals	0.080^{+}	Used Ideas From Peer	0.105^{*}
Stuck Tough	0.145^{**}	Chose To Learn	0.171^{***}	Worked With New Peer	0.111^{*}
Got Curious	0.103^{*}	Gave Feedback	0.180^{***}	Helped Brainstorm	0.068
Asked Questions	0.087^{*}	Sought Feedback	0.157^{***}	Helped Peer	0.064^{+}

$^{***}p<.001$; $^{**}p<.01$; $^{*}p<.05$; $^{+}p<.10$

At the same time, with the exception of "Taking things apart" (*r*=.09*), no project exposure relation was found for design thinking and problem-solving outcomes. Though correlational and therefore not causal, this result suggests that students can benefit from intentional focus on aspects of design thinking in environments like the Learning Studio. "Taking things apart" was central to two project guides—"Parts, Purposes and Complexities" and "Toy Workshop". In these projects, students chose an object to observe and carefully deconstruct in an effort to understand its purpose, function, and operating mechanisms. In the Toy Workshop project, students learned to create small, interconnecting parts and then use the parts to create toys or playful objects of their imagination. In contrast, for the other indicators of design thinking and problem solving, the number of projects completed did not seem to have an impact relative to other activities teachers implemented with students in the Learning Studio.

For a second look at project implementation effects, we tested whether teachers' responses to a selection of follow-up survey questions differed between those who had or had not chosen to implement the Play to Learn Challenge with their students. Results are presented Tables 18-19. For a variety of questions across the four focal outcomes, responses of teachers who implemented the Play to Learn Challenge were higher across the board, with the majority reaching statistical significance notwithstanding a small sample size.

Table 18: Follow-up Comparisons for Teachers' Play to Learn Challenge Implementation

		YES		NO		
		Mean	sd	Mean	sd	
Focal Outcome	**Through participation in the Learning Studio:**					
Agency	... I gained more comfort in leading projects in which students have a high degree of autonomy	4.50	.535	4.26	.562	$t(25)=1.014$
Design	... I grew in my ability to lead students in the design process	4.63	.518	4.16	.688	$t(25)=1.718^{*}$
Skills	... my students learned valuable new skills	4.88	.354	4.53	.513	$t(25)=1.746^{*}$
Empathy	... my students improved in their perspective-taking ability	4.63	.518	4.26	.653	$t(25)=1.388^{+}$
Collaboration	... my students became better collaborators	4.88	.354	4.53	.513	$t(25)=1.746^{*}$
Communication	... my students improved in their ability to communicate their ideas to others	4.88	.354	4.37	.597	$t(25)=2.225^{**}$
Empathy	Taking part in the Learning Studios program helped my students to develop their knowledge and understanding of the world.	4.38	.518	4.00	.667	$t(25)=1.416^{+}$
Engagement	Some students who are not typically engaged in classes really got into the Learning Studio projects.	4.38	.518	4.26	.733	$t(25)=0.39$
Engagement	Students put in more time than was required on their Learning Studio projects	4.13	.641	3.89	.809	$t(25)=0.713$
Agency	The Learning Studio projects had personal meaning for students.	4.63	.518	4.21	.713	$t(25)=1.48^{+}$

Table 19: Play to Learn Challenge: Implementation Effect for Focal Indicators: Feedback

	YES		NO		
	Mean	sd	Mean	sd	
Through the Learning Studio projects, students gained facility in:					
requesting feedback	4.50	.535	3.737	.733	$t(25)=2.649^{**}$
offering feedback	4.43	.535	3.842	.501	$t(24)=2.601^{**}$
integrating feedback	4.25	.707	4.00 0	.471	$t(25)=1.083$

Teacher Background and Experience. The second set of analyses examined patterns in student outcomes in relation to teacher background and experience with technology and design thinking, using the groupings described in section 3.1 (See also Appendix B). The first group (Beginning), while evidencing enthusiasm and buy-in for the Learning Studio project, came with little background in making and did not indicate prior exposure to or awareness of design thinking principles or strategies. The second group of teachers (Emerging) described some personal experience with making, and generally did not bring experience facilitating students in making or design thinking. The third group (Intermediate) brought both personal and professional experiences with design, having facilitated student making projects, including robotics clubs and other initiatives. The fourth and final group of educators (Advanced) evidenced knowledge and experience of the design process, situating making within a larger culture of pedagogy related to project-based learning. Since students from teachers categorized in group 2 did not complete the post survey, the analyses compared groups 1, 3 and 4.

To explore whether student outcomes were related to teacher groups, we carried out several one-way ANOVAs with LSD post-hoc pair-wise comparisons using Bonferroni corrections. Figure 29 provides a legend for reading the visualizations used to present the results of the group comparisons, which appear in Figures 30 through 34.

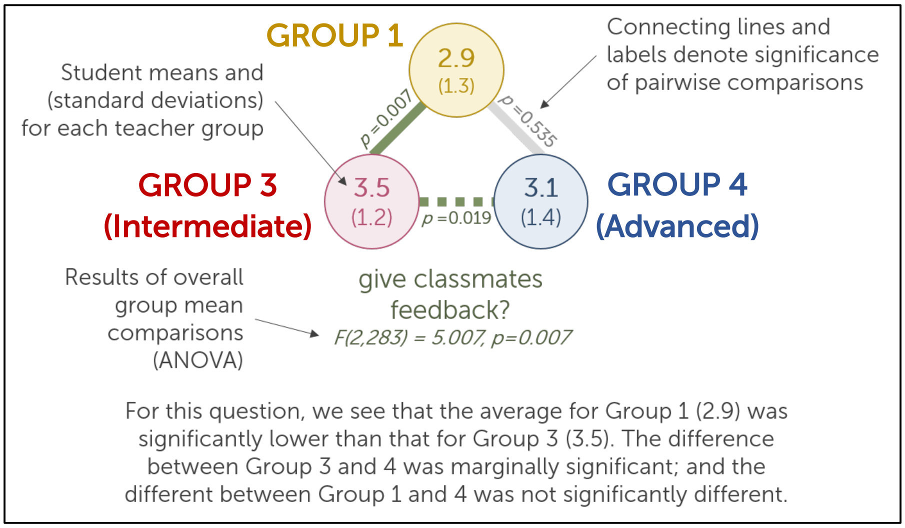


Figure 29: Legend and Guide for the Teacher Group Data Visualizations

The first group comparison examined the extent to which students' sense of identity as a designer or maker differed across teacher groups. As can be seen in Figure X, notable differences are present between group 1 relative to groups 3 and 4. For example, whereas at post-survey the average response to "Are you a Maker" for students of teachers in group 1 was 2.8, for students of teachers in groups 3 and 4 the averages were 3.6 and 3.8, respectively. These differences were highly statistically significant. In contrast, statistically significant group differences were not detected for students' overall ratings of confidence with making activities and processes (not illustrated).

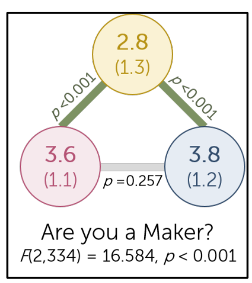


Figure 30: Student Maker Identity x Teacher Groups

We also explored patterns between students' use and comfort with the technology and teacher background (Figures 31 and 32). We found that students' Sprout use and comfort varied by teacher group, with students associated with group 1 having significantly lower use of the Sprout relative to students associated with groups 3 and 4. Students' comfort using the Sprout, and teaching others to use it, was highest for those associated with group 4; however, the average responses for groups 1 and 3 were statistically equivalent. Regarding use and comfort with the 3D printer, average responses for students of group 4 teachers were higher across all four indicators relative to groups 1 and 3.

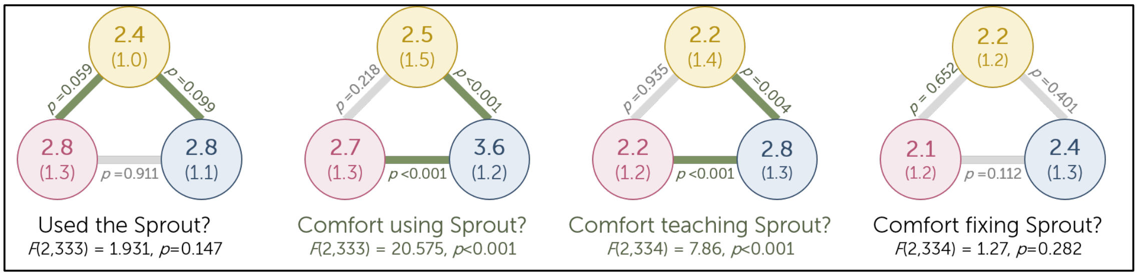


Figure 31: Student Sprout Outcomes x Teacher Groups

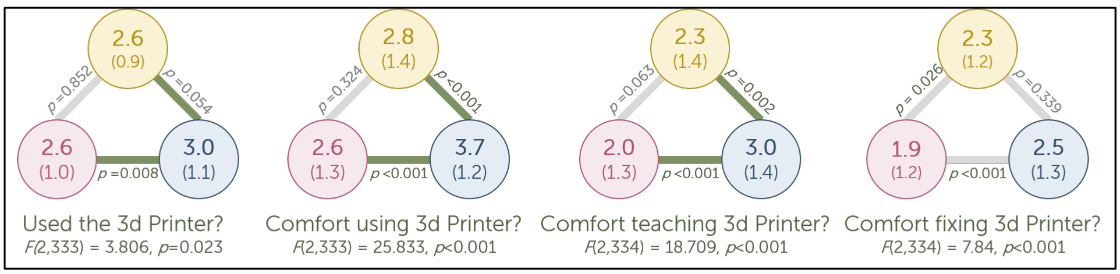


Figure 32: Student 3D Printer Outcomes x Teacher Groups

Notably, students taught by educators in Group 1 had significantly lower Maker Mindset averages than did those taught by educators in Groups 3 and 4. Similar analyses were carried out to compare students' post-survey responses for agency and initiative. Interestingly, students of teachers in group 3 posted the highest averages for these dimensions of Learning Studio experience, relative to other students. Figures 33 and 34 present the results.

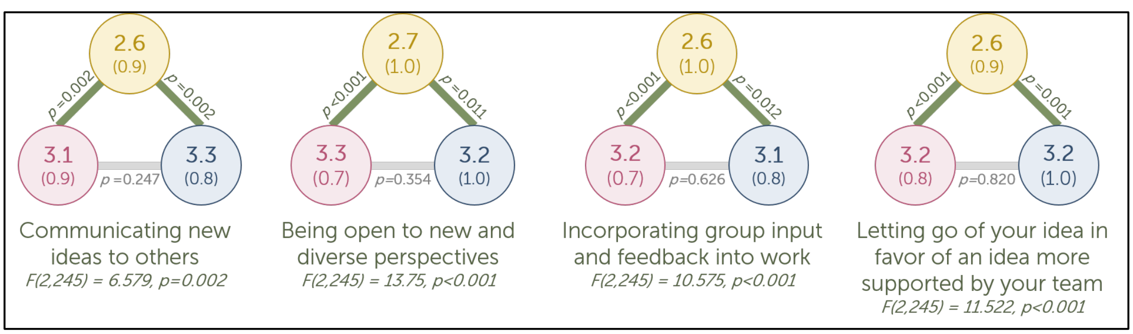


Figure 33: Empathy, Communication and Collaboration x Teacher Groups

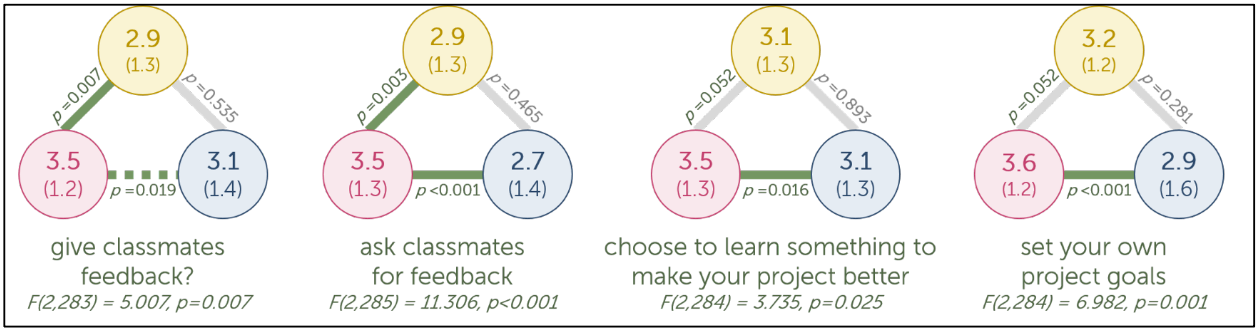


Figure 34: Student Agency and Ownership of Learning x Teacher Groups

3.7 Program Reach

In this final section on results, we present some additional findings regarding overall program reach, as well as teachers' and students' overall perceptions of the Learning Studio program. In total, this first implementation of the Learning Studio program reached well over four thousand students. Teachers reported that 2,286 students participated occasionally in the Learning Studio, 1,133 students participated regularly, and 805 were avid participants.[2] Among all participating students, teachers estimated that 326 were students with documented learning disabilities.

Global Initiative. A hallmark of the Learning Studio program was the inclusion of international implementation sites, with opportunities for teachers and students to connect and even collaborate across classrooms. The follow-up survey included questions to teachers regarding the global nature of the program for their own professional development and program experience, as well as for their students' learning. Overall, we found moderate support for this aspect of the program. The large majority (85%) of the 27 teachers who completed the follow-up survey agreed that taking part had helped their students to develop their knowledge and understanding of the world; half (52%) felt the international scope of the program had added value to their students' experience. In terms of their own experience, more than three-fourths of teachers (77%) agreed that taking part in the Learning Studios global online professional learning community network had positively impacted their practice; 19% strongly endorsed this outcome. Seven in ten felt that their experience had been enhanced by the participation of teachers and students from other countries. Teachers' ratings of the value of the online community were mixed, with 61% expressing agreement, 31% remaining neutral, and 8% indicating disagreement. At the same time, there was some evidence in interviews that increasing cross-site collaboration was a desirable future goal for teachers.

Ripple Effects. Teachers also described how their implementation of the Learning Studio had ripple effects throughout the school and district. A second-grade teacher explained, "I see it growing and spreading. We did a couple making activities with the

[2] Teachers interpreted the labels "avid", "regular" and "occasional" for themselves when responding to this question.

whole second grade and that started growing throughout the grades and now other classes, it's started spreading in other grades. People are talking about paper circuits. It seems you start with a project or one classroom even and the kids can't help but be excited and tell other people about it and pretty soon lots of people are doing catapults and lots of people are doing little making projects. I've seen it really expand in my school. Now everyone is asking about 3D printing."

For one district in particular, the introduction of the UN Sustainable Development Goals in the Learning Studio led to a new culture. "In the very beginning [the Learning Studio team] said, we will base the projects on the UN Sustainable Development Goals. I brought that back to my team and now we use those Sustainable Development Goals throughout the whole district. We're always looking for real-world questions for kids, and by default those are amazing real-world questions. And the kids say, 'It makes us feel that what we are doing is important. These are the things that the leaders of our world think we need to work on. And so we're working on them, too.' That was the perfect reason to embrace that."

4. Limitations

As with all studies, several factors impact interpretation of findings and limit the extent to which the outcomes can be generalized to a broader population. One consideration in interpreting the outcomes reported here is whether the changes we observed can be attributed to the intervention itself, or whether other factors may have been responsible for the effects found. In situations where the program under examination is well defined and implemented in comparable contexts, changes can be confidently attributed to the program. These attributions are harder to justify when implementation differs substantially with respect to program definition and participant characteristics at each site. Because the Learning Studio was first and foremost a program offering, implementation decisions were driven by factors other than research design. This led to amplification rather than restriction of factors other than the Learning Studio that varied from site to site, and posed challenges to isolating key influences and causes.

One limitation therefore pertains to the fact that we did not study a specific intervention, but rather a broad spectrum of choices at each site in how to utilize the technology and resources provided by the program. As seen in preceding sections, the open-ended nature of the Learning Studios, in which each teacher chose which projects to implement, if any, resulted in substantial variability in the nature and amount of student exposure. Moreover, these project choices interacted with an array of instructional contexts. In some cases, Learning Studios primarily enhanced the technology tools at students' disposal within existing classes in entrepreneurship, or in engineering, such as Project Lead the Way. In other cases, maker learning programs were already underway and the Learning Studio contributed to ongoing expansion of that effort. And at some sites the Learning Studio introduced design technologies for the first time, in contexts that had previously prioritized large-group direct instruction with students. Consequently, what was meant by "Learning Studio" was very different from site to site, with important implications for making sense of the data we gathered. For instance, it is possible that averages across the program were largely driven by gains in a couple classrooms; moreover, changes in those classrooms could have been due to processes already underway to drive student growth in design thinking. Sample sizes and large differences in number of students who responded from site to site constrained our ability to carry out meaningful class-level or teacher-level analyses.

Lack of uniformity in participant characteristics is a further issue to weigh in interpreting the results. Teachers at each site differed in important ways, from their personal and pedagogical experience with design thinking and making to their experience and comfort with advanced technology. Moreover, grade levels spanned elementary through high school, and students had varied prior exposure to robotics, making, and engineering programs. When coupled with the differences in the Learning Studio program itself, this variability posed additional challenges to interpretation. In any study, the more that participants differ from one another within a variable intervention model, the harder it is to isolate the effects of the program and to obtain an accurate read on salient implementation features and contextual characteristics.

Further considerations include response rates and instrumentation. As is typical of implementation research, we saw relatively low response rates, particularly for the follow-up survey, which limited our ability to identify trends over the full duration of the project. Moreover, many students who hadn't used the equipment responded, as revealed in students' responses on the post survey. Also on the post survey, via open-ended responses a notable number (4%) of students indicated that they hadn't been to the Learning Studio or started the project yet. Results may have been diluted by the responses of students who didn't experience the full implementation of the Learning Studio at their school.

Finally, the research was limited by the lack of established measures and methods for studying making and design-based learning. The survey items we used may not have been sufficiently sensitive to the impacts that were caused by the Learning Studios. Perhaps more fundamentally, a potential limitation of the study was the decision to rely primarily on quantitative survey items to explore Learning Studio effects. This choice was driven in part by an interest in contributing to a base of evidence demonstrating the positive impacts of design thinking programs. In addition, the program design anticipated the specific outcomes for which we administered survey items. Because quantitative approaches are well suited to the participation of large groups, they are a good choice when the goal is to generate evidence regarding specific hypotheses about impact and the role of context. On the one hand, it could be argued that what we found through survey data is that simply providing Learning Studio package is not universally sufficient to generate impacts. Another perspective is that it was too early in the arc of studying the benefits of design thinking programs to focus on hypothesis testing, and that a primarily qualitative approach may have afforded more opportunities to uncover trends and insights.

5. Insights for Future Implementations

As referenced in several places in this report, the Learning Studio was a highly open-ended program, and implementation at each site reflected a great deal of diversity. This variation is important to consider when interpreting results and drawing insights that could assist in future implementations of this and related programs. Overall, while we found evidence for a range of positive benefits associated with the Learning Studio program, these benefits were not universal across all students. Measurements of growth from pre to post, using both quantitative as well as qualitative items, yielded more conservative estimates of impact than did questions regarding students' and teachers' perceptions of growth at the end of the program.

We were curious to understand the conditions in which students drew the most benefit from their Learning Studio experience. As described in Section 3.6, we found that one explanation for differences in student outcomes was teacher background, and another was the extent to which students used the Learning Studio project guides. From interviews, we noticed that differences in teachers' prior experiences with designing and making translated into different kinds of classroom culture, which were potentially responsible in turn for differences in student outcomes. Table 20 describes the general patterns that emerged from the overall data set.

Table 20: General Patterns in Contextual Factors and Student Outcomes

Teacher Background	Teacher Comfort	Instructional Focus	Student Experience	Student Outcomes
Limited design thinking and PBL	- Low to moderate comfort - Low to moderate comfort as facilitator	- Technology Use - Production of objects - Teacher-defined projects	- Procedural - Somewhat collaborative	- Tech skills - Collaborative attitudes
Prior experience with design thinking and PBL	- High tech comfort - High comfort as facilitator	- Strengths-based - Student agency - Identification of problems to solve	- Student-driven - Collaborative - Iterative	- Tech skills - Persistence - Identity as Designer/Maker - Collaboration abilities - Design thinking

Overall, it appeared that the nature of program benefits depended on whether the context was an emergent or established Learning Studio environment. In what we could call "emergent" contexts, the focus tended to be on developing technology skills and executing specific assignments. This could be seen in the ways that teachers at these sites described the implementation, and in students' open-ended responses about what they had learned in the Learning Studio. In "emergent" settings, another benefit of the Learning Studio was to open new possibilities for the uses of technology as well as for the importance of fostering students' non-cognitive skills such as collaboration, time management, persistence and problem-solving ability. In contrast, in "established" Learning Studio contexts, some elements of student-driven learning, design thinking and collaboration were in place prior to program implementation. In these settings, the Learning Studio enabled greater design focus and cross-site collaboration than previously experienced. While the outcomes at "established" sites were generally stronger, the Learning Studio was one of many causal contributors; in "emergent" sites, Learning Studios served a larger role as a catalyst for new ways of engaging students in 21st century competencies.

For example, at one "emergent" site, a major focus was the production of cookie cutters by all students at the school. In focus groups at this site, most students characterized their experience of the Learning Studio as fun but offered little evidence regarding growth in problem solving or design thinking. An educator from this site noted that the introduction of the Learning Studio at the school revealed the extent to which students' prior classroom experiences had failed to develop their collaboration skills. He found that through the Global Goals, Local Solutions project, students came to realize the value of working with others to be successful. In contrast, at "established" sites, Learning Studio lead teachers had already created classroom environments in which students were actively encouraged to take risks, were provided with many opportunities for authentic group work and collaboration, and were focused on identifying meaningful problems to solve. For these teachers, the Learning Studio enabled them to enhance their students' design thinking and collaboration skills.

A related insight from the research is the apparent relationship between teachers' own comfort and familiarity with technology and design-based learning, and the nature of the experiences they offered students. These differences were independent of a willingness to implement the Learning Studio, which all the teachers seemed to take on eagerly. For example, at an emergent site, the lead educator shared that rather than focus on student outcomes in this first implementation, his goal was to enable teachers to build their own comfort with this new paradigm for teaching and learning. In some cases, teachers' own lack of comfort translated to reluctance to allow students to explore the technologies on their own.

One perspective on the Learning Studio program is that it represents an effort to scale the "Maker Movement" and design-based thinking into formal learning environments. As is true for any expansion of an initiative from organic growth to systemic adoption, the drivers of successful implementation may be different, and may carry new implications for program design. Until recently, “makerspaces” were primarily born of an educator’s personal passion for designing and making. It is likely that individuals drawn to the “do it yourself” and design communities share characteristics such as an openness to risk-taking, comfort with students experimenting, and a commitment to interest-driven project work. Indeed, as shown in Appendix E, teachers in our study who indicated prior experience leading design thinking and makerspaces reported significantly higher levels of comfort across a number of the skills and abilities we surveyed. Moreover, teachers’ experience leading makerspaces was related to their persistence in the Learning Studio, as measured by completion of later surveys. Close to twice as many teachers with prior experience completed a post or follow-up survey (38%), compared to 22% of teachers without prior experience.

When the idea of a makerspace or learning studio goes to scale, the same assumptions are unlikely to hold – whether for the educators or for the participants themselves, who are no longer volunteers but required. To the extent that robust outcomes are valued, this context of “scaled” organic implementation may demand a more intentional approach to developing design thinking, and moving educators and learners along a trajectory from technology skills and production focus toward a culture of maker mindset, design, and iterative problem solving.

In light of these observations and the findings from this report, we identified four main areas of insights for future implementations.

1. Time and Technology

Comfort with technology grows over time. Making sure teachers have ample opportunity to familiarize themselves with the technology, and ensuring that the right infrastructure is in place, can be a simple way for teachers to build their personal comfort before being in the position to facilitate students’ use of it. In our study, many teachers noted that time was a critical factor, and expressed the desire that there had been more lead time—whether for getting the technology fully set up, for familiarizing themselves with the basics, or for introducing students to foundational knowledge and attitudes in a design-based learning paradigm. This latter mindset appeared more difficult to influence in older students relative to younger students – likely due to their longer-term exposure to expectations and mindsets of traditional instructional models over years of schooling. Related to time, teachers also noted the importance of full buy-in and expectation-setting at the school and district level, to ensure that the needed technology supports were in place for the software and hardware.

2. Professional Development and Mentorship

Findings related to teachers' facility with advanced technology, and especially with design thinking and problem-solving processes, suggest that an important focus for future implementations is extended professional development opportunities for teachers, both prior to and during implementation. This support could take a variety of forms. One option is for teachers to take part in hands-on experiences with the projects, ideally in a group setting, with an experienced educator serving as a model for facilitating the process. Many teachers are unfamiliar with common design thinking processes and human-centered design practices. As such, they are in the challenging position of being expected to discover best practices on their own, without the benefit of wisdom from those who have been through the process many times. While each teacher's learning will still reflect a personal journey, exposure to best practices can accelerate their learning curve. Findings from this study suggest that the more teachers have some personal experience and have developed their own mindsets reflective of design thinking, the more likely their students are to take on these practices as well.

Teachers shared that additional mentorship could be beneficial. Although the Learning Studio offered an online discussion and sharing site, most teachers did not engage deeply with it. One teacher noted the difficulty of developing effective working relationships in the virtual large-group format, which can remain somewhat anonymous particularly when teachers have not met in person. One model that met with enthusiasm from teachers we talked to is a small professional learning community (PLC) of two advanced and two novice teachers, who share insights and tips. Some teachers were eager to increase the level of student-to-student collaboration across sites, which could also be accomplished within a small PLC.

3. Intentional Instruction

The role of pedagogy is another important consideration for future implementations. One perspective is that providing teachers and students with access to technologies and activity prompts will necessarily lead to substantive growth in the kinds of abilities described by the focal outcome areas, such as design thinking, empathy and student ownership of learning. Beyond improved technology skills and comfort, the results of this exploratory study do not bear that hypothesis out. Instead, the data suggest that intentional instruction is an important context for students' development of design thinking and related competencies. This is especially likely to be the case when students have not self-selected into the Learning Studio experience, and may be more naturally drawn to interests other than designing and making activities.

The teachers in our study who described the most impressive gains in students' persistence, collaboration, and other skills were those with pedagogical practices specifically targeting these areas of growth. For these teachers, the Learning Studio program provided occasion to continue, enhance and deepen. At sites where a design thinking culture was not already present, the nature of gains was more modest and concentrated in technology skills, with some progress in collaboration and communication. While traditional direct instruction would not be in keeping with a design thinking or maker philosophy, *intentional* instruction—in which students are facilitated to extract a design process that includes understanding the problem situation, identifying root causes, prototyping and testing–appears key to fostering student growth. This insight is further demonstrated in the fact that the more project guides teachers used, the more students demonstrated growth in the focal outcomes.

A related perspective on pedagogy is the value of setting expectations for students' learning in advance. Expectations could range from completely open—including the possibility that students take little from the experience—to more specific, such as a focus on aspects of collaboration, or design thinking, or the development of empathy. By articulating expectations prior to implementation, educators can craft a Learning Studio experience that facilitates those expectations and ensures ample opportunity for students to grow in valued competencies. This is especially true of implementations in formal educational environments where there is a mandate to engage students in experiences that contribute to their learning and growth.

4. Scope of Implementation

Learning Studio sites differed in the scope of their implementation. In some cases, entire grade levels were involved; other programs focused on a small group of students. Figuring out the right grain-size for initial implementation is an important consideration to weigh. Our observations suggest that starting on the smaller side of the spectrum, and ensuring that teachers have ample opportunity to grow their own confidence and comfort levels, lead to the greatest student gains. Future renditions of the Learning Studio might include recommendations for scope tied to the extent of prior design projects, as well as teachers' own facility in a design-based learning environment.

6. Recommendations for Future Research

This exploratory study into the implementation and impacts of the Learning Studio program yielded a variety of insights, and gave rise to additional questions for future research to pursue. As the results presented in this report show, design-based learning experiences like those afforded by the Learning Studio offer promise and potential for student learning and for the development of the "non-cognitive" skills—such as persistence, collaboration and problem solving—that are increasingly recognized as important to life success. There is a need for more studies to provide compelling documentation of the value of these programs. Achieving this goal requires a research agenda comprising multiple studies to qualitatively gather more nuanced understandings of the role that context and implementation models play in fostering teacher and student outcomes; subsequent large-scale research using quantitative methods are also needed to confirm and validate patterns.

Among avenues for additional inquiry are the role of intentional instruction for promoting aspects of design thinking in students, and the best practices for growing teachers' comfort and confidence in a design-based instructional paradigm. Another question that arose in interpreting results, and even in setting out the initial goals for the program, was determining a reasonable level of change to expect in teachers and students after only a few months of implementation, and with various levels of support. Future research could document typical trajectories of growth in design thinking, including the amount of time it takes to develop at different grade levels, and the characteristics of instruction that are most conducive to students' engagement as well as learning.

As outlined in earlier sections of this report, isolating the effects of a specific program or contextual factor is difficult to do when the program is broadly defined, and participation contexts vary greatly. A related factor is the choice of method for the research. Among opportunities for future studies is the revision and validation of survey instruments to ensure that teachers and students are interpreting items as intended, and that response scales offer a range of responses sensitive to changes in attitudes, beliefs and competencies. Given the known issues with self-report data, the development of additional performance tasks for technology, collaboration, design thinking and problem solving would represent an important contribution to the field.

7. Conclusion

This paper presented findings from exploratory research of a one-year Learning Studio implementation at diverse sites in the United States and abroad. Results from quantitative and qualitative analyses suggest that many participating teachers and students grew in several aspects of advanced technologies and design-based thinking, and that access to the Sprout and 3D printing technologies opened new opportunities for students' creativity and iterative problem solving. Findings also indicate that teachers' background and students' design-based behaviors are related, and that higher levels of teacher comfort with design thinking processes and technologies are predictive of students' growth. Importantly, the evidence gathered through this research shows the potential of projects like the Learning Studio to have positive impacts on key skills and beliefs for students of the 21st century. We hope that the insights and questions raised in this report will contribute to ongoing efforts to bring opportunities like the Learning Studio to all children.

8. References

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APPENDIX A

Sample Project Guides from the Learning Studios Teacher's Guide

Custom Cookie Cutter

Make your own cookie cutter – choose a design that you like and think that you will be able to model. Teachers Guide | Student Guide

Toy Workshop

Make a toy! Now that you've had some experience with interconnecting pieces, build your own toy using stiff joints, loose joints and ball joints. Teachers Guide | Student Guide

Global Goals, Local Solutions Design Challenge

Participating sites around the world are invited to take part in a culminating 2016 Learning Studio Global Goals, Local Solutions Design Challenge. Entries can take any form – from devices to media campaigns to processes - anything students can imagine that incorporates their creativity, designs, and skills to address real-world issues that matter to them. Challenge Guide

Play to Learn Design Challenge

How might we create a digital or analog game to help the player(s) learn something new? Teachers Guide | Student Guide

APPENDIX B

Selections of Teacher Pre-Survey Responses Representing Each Grouping

		Ways I expect to change personally	How will students grow?	What will students learn?
Group 1: Beginner (enthusiastic but new to maker learning)	US 7	I feel that the Learning Studio will truly push my classroom into the 21st century	We hope they grow and expand their innovative thought and have a place to apply them and not just dream.	I hope students will learn to be innovators and enjoy learning. In addition, learning goes beyond textbooks.
	US 678	I love to learn about new technology and ways to keep students engaged	Locating the Learning Studio in the library will be an additional way to keep students engaged in the many activities/events we have throughout the year.	Creating projects can be [an] excellent way to blend/apply skills from a variety of curriculum areas.
	US K5	I expect to become more comfortable with incorporating technology into the classroom setting.	I think they will grow with their confidence.	I hope they learn how to collaborate and think creatively.
	Int 6 10 12	Change the style and methods used in the classroom at the moment	Get connected to and share ideas with other Learning Studio students of different parts of the world.	Development of IT competencies, social competencies, improvement of presentation techniques.
Group 2: Emerging (some personal experience with making,	US 11 12	New experiences and learnings	In creativity and willingness to learn from mistakes	How to learn to ask the right questions to solve problems

but new to design process)				
	Int 10-12	I expect learning a lot about new methods of teaching and new ways of interaction with my students.	They will take advantage of this project as a way to cooperate with others and I'm sure that they will progress a lot in their development as future adults.	New ways of learning, in collaboration with others, involving the entire community in the [creation] of knowledge
Group 3: Intermediate (focus and experience with students' making; design thinking not explicit)	US 5	Shifting more to student-centered learning even more so than I already use.	I hope they will develop a love for building and computer sciences.	Creative thinking and independence with technology.
	US 11 12	I will enjoy learning to use 3D technology and reacquainting myself with CAD. I will also enjoy learning how to introduce project-based learning into my curriculum.	Students should become more empowered to take control of their own learning because they can see how it is relevant to practical applications in which they have an interest.	How to self-regulate. How to organize a group to maximize productivity by leveraging strengths (...). I hope students will learn how to use the current technology in the learning studio to manifest their creative ideas.
	US 9-12	I hope to transform my library from a place of only consumption of information to a creation studio. I want students to talk, create, dream, share, and innovate together.	I hope they will grow with each other and the collaboration teaches them how to work as a team, ask for help, use resources, find resources, and to not be afraid to change	That school is more than just answering questions on a test or writing an essay. That inquiry and problem solving and creating is important. I hope they learn that technology is a powerful tool that can enable

			the world!	them to share their gifts but innovation comes from within.
	Int 7-12	More confident with new technology	Develop skills to A level .. build on these and transfer across other subjects.	How to integrate new technology to support and enhance problem solving/modelling and realisation of ideas.
Group 4: Advanced (background in project-based learning; awareness of design process)	Int 456	Comfortable with the new technology; integration of learning areas to still cover required concepts in math/sciences/technolo gy	Form new friendships; develop interpersonal skills; improve communication skills	Understand the technology; improved collaborative learning; new insights into science/math/technolog y concepts; a better understanding of the design and marketing process in the real world; cooperative communication skills
	US 2	I expect people to get excited about the maker movement and 21st century learning. I expect people to seek further knowledge about Learning Studio and find ways to benefit from it.	I hope students learn how to be a successful global learner.	I hope students will fall in love with learning. I hope students will develop a growth mindset. I hope students will learn how to persevere (how to fail but recover and succeed). I hope students learn to be thinkers and problem solvers. I hope students learn how to be producers of their dreams.

	US 678	I think I will be growing as an educator to move more from demonstrating and lecturing to a facilitation role and allowing students to be more "in charge" of their own learning.	I want them to learn the technology skills inherent in using the Sprout, and the 3D printer, but I think the biggest thing I want them to come away with is the change in thinking—to be more independent, to question, to believe that they can make change.	I hope students will learn to use the design thinking models, and become creative risk-takers.

APPENDIX C

Students' Comfort with Learning Studios Equipment – *Without removing students who had used the Sprout or 3D printer at least once by POST or FOL*+

	PRE		POST		FOL		PRE-POST	PRE-POST-FOL
	Mean	Sd	Mean	sd	Mean	sd		
- Use	2.92	1.480	3.23	1.367			$t(400)=4.208^{***}$	
	2.40	1.450	2.72	1.469	2.95	1.542		$F(2,84)=3.254^{*}$
- Teach	2.22	1.329	2.60	1.336			$t(400)=5.283^{***}$	
	1.88	1.313	2.12	1.331	2.63	1.619		$F(1.683,70.695)=4.930^{*}$
- Fix	2.18	1.248	2.39	1.242			$t(400)=3.335^{**}$	
	1.84	1.067	1.98	1.144	2.56	1.517		$F(1.743,73.223)=7.534^{**}$
3D printer								
- Use	2.99	1.469	3.23	1.368			$t(400)=3.178^{**}$	
	2.42	1.468	2.63	1.363	2.74	1.432		$F(2,84)=1.021$ (ns)
- Teach	2.25	1.364	2.59	1.394			$t(400)=4.558^{***}$	
	1.91	1.411	2.02	1.406	2.4	1.514		$F(1.616,67.859)=2.067$ (ns)
- Fix	2.12	1.197	2.24	1.243			$t(400)=1.796^{*}$	
	1.88	1.159	1.74	1.026	2.35	1.462		$F(1.557,65.396)=4.308^{*}$

+ 5-point response scale ranged from 1 ("not at all comfortable") to 5("totally comfortable").
$^{**}p<.01$, $^{*}p<.05$, ns = not significant

APPENDIX D

Overall and Grade-Level Pre-Post Changes in Student Comfort with Communication and Collaboration Indicators

	PRE		POST		FOL			
	Mean	sd	Mea n	sd	Mean	sd	PRE-POST	PRE-POST-FOL
Communicating new ideas to others	3.08	.834	3.07	.878			*t*(304)=.066 (ns)	
	3.26	.795	3.08	.784	3.34	.745		*F*(2, 73.89) = 2.337
Being open to new and diverse perspectives	3.13	.865	3.21	.825			*t*(304)=1.379 (ns)	
	3.47	0.60 3	3.42	.642	3.50	.558		*F*(1.94, 71.68) = 0.214
Incorporating group input and feedback into work	3.10	.786	3.06	.821			*t*(304)=.830 (ns)	
	3.21	.664	3.18	.652	3.45	.645		*F*(1.98, 73.25) = 2.356
Letting go of your idea in favor of an idea more supported by members of your team	3.11	.282	3.01	.881			*t*(304)=-1.750 (ns)	
	3.21	.777	3.13	.665	3.50	.647		*F*(1.94, 71.79) = 4.209*

APPENDIX E

Teachers' Comfort for Those with and without Previous Makerspace experience

Previously led maker space or design thinking programs?	No (n=22-23)		Yes (n=37-39)		
PERSONAL COMFORT	mean	sd	mean	sd	Yes-No Comparison
Using a Sprout computer	1.74	.964	2.36	1.088	t(60)=2.258*
Using a 3D printer	1.78	.902	2.62	1.042	t(60)=3.190*
Taking something apart to see how it works	2.70	.926	3.46	0.790	t(60)=3.459**
Using drawings and/or models to share an idea	3.09	.900	3.67	0.530	t(60)=3.200**
Recording and editing an audio or video recording	3.00	1.044	3.56	0.680	t(33.185)=2.316*
Creating a digital 3D model of an object	1.91	.868	2.67	1.009	t(59)=2.957**
Assembling something WITH instructions (ex IKEA furniture or a Lego kit)	3.36	.848	3.79	0.522	t(30.185)=2.166*
Assembling something WITHOUT instructions	2.35	.982	3.33	0.806	t(60)=4.287***
Defining problems to investigate	3.22	.671	3.62	0.590	t(60)=2.437**
Working effectively when process is variable or ambiguous	3.09	.596	3.51	0.644	t(60)=2.584**
Communicating new ideas to others	3.74	.541	3.79	0.409	t(60)=0.459
Being open to new and diverse perspectives	3.87	.344	3.97	0.160	t(27.708)=1.374+
Incorporating group input and feedback into work	3.65	.573	3.72	0.456	t(60)=0.498
Letting go of your idea in favor of an idea more supported by members of your team	3.26	.541	3.58	0.552	t(59)=2.198*

	No (n=22-23)		Yes (n=37-39)		
COMFORT FACILITATING STUDENTS	mean	sd	mean	sd	Yes-No Comparison
Using a Sprout computer	2.05	1.133	2.34	1.072	t(58)=1.012
Using a 3D printer	2.14	1.125	2.63	1.125	t(58)=1.643+
Taking something apart to see how it works	2.81	.680	3.26	0.860	t(49.927)=2.228*
Using drawings and/or models to share an idea	3.32	.780	3.68	0.471	t(30.047)=2.000*
Recording and editing an audio or video recording	3.14	.889	3.51	0.731	t(57)=1.767*
Creating a digital 3D model of an object	2.14	.834	2.57	1.119	t(53.97)=1.686*
Assembling something WITH instructions (ex IKEA furniture or a Lego kit)	3.45	.739	3.79	0.528	t(33.598)=1.869*
Assembling something WITHOUT instructions	2.45	.858	3.21	0.843	t(58)=3.325***

Defining problems to investigate	3.41	.590	3.55	0.64 5	t(58)=0.856
Working effectively when process is variable or ambiguous	3.27	.456	3.34	0.70 8	t(57.247)=0.461
Communicating new ideas to others	*3.82*	*.395*	*3.68*	*0.574*	*t(56.123)=1.067*
Being open to new and diverse perspectives	*3.91*	*.294*	*3.79*	*0.474*	*t(57.65)=1.205*
Incorporating group input and feedback into work	*3.73*	*.456*	*3.68*	*0.525*	*t(58)=0.321*
Letting go of your idea in favor of an idea more supported by members of your team	*3.59*	*.590*	*3.55*	*0.555*	*t(58)=0.252*