Initial Data from the Learning through Making Instrument [NSF RFE program]

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In recent decades, makerspaces have seen a surge in growth as a place to expand and implement skills in design, fabrication, and assembly [1]. More recently, several Higher Education Institutions (HEIs), particularly those with large engineering cohorts, have sought to include makerspaces within their institutions to teach students hands-on skills within engineering, design, and manufacturing [1], [2], [3]. By expanding access to and the capabilities of makerspaces, students are able to gain a better "hands-on" understanding of these skills and harmonize them with a more formal or theoretical education. One analysis estimated that there were over 1000 active makerspaces worldwide in 2016—a 14x increase from a decade prior [4]. Another analysis found that, in 2019, over 41% of state colleges and universities in the U.S. had or were interested in having a makerspace [5]. However, despite considerable research on the positive impacts of these spaces on the learning and educational outcomes of students [6], an instrument for scalable, consistent evaluation of the learning effectiveness of these spaces has yet to be developed.

The Learning Through Making Instrument (LMI) project seeks to fill this gap. Through funding from the NSF's Research in the Formation of Engineers (RFE) program, the LMI project aims to develop a quantitative instrument that can fairly, reliably, and accurately measure several key aspects of makerspaces at HEIs, such as their impacts on students' learning processes and outcomes. The LMI survey measures five learning constructs: learning by doing, learning by others, content knowledge and skills, cultural knowledge and skills, and ingenuity. This paper details the progress our team has made in the project over the last year.

General overview and progress made in the last year

The project was divided into five distinct phases, each shown in Table 1, spanning from the identification of a theoretical background to validity and reliability measures of the instrument and how to interpret its outputs. The first two phases focused on creating a theoretical framework and generating items of interest for the LMI project. These phases involved rounds of feedback with experts in the fields of makerspaces and instrument development, as well as think-aloud interviews with students. The work done on phases I and II is further detailed in other publications [7], [8], [9].

As a result of Phases I and II, we created a pilot survey, which we used for our first validation study (Phase III) over the course of the past year. At the beginning of the first validation study, the survey was piloted at two U.S. institutions—one in the Midwest and one in the South—each with large engineering populations, several well-equipped and well-supported makerspaces, and a large number of makerspace users. This pilot survey measured six learning constructs by posing 40 statements (items) to which the respondent would indicate how much the statements represented their makerspace experiences on a five-point scale that ranged from "not at all" to "completely". We collected 375 high-quality responses in this phase from engineering students enrolled in courses that include makerspaces as a learning component and from general users of makerspaces on these campuses.

Table 1

Status of study phases and main outputs.

Phase	Goal	Status	Outputs
I: Construct theory and definition	Define constructs to be measured with the instrument.	Complete	Constructs. Process documented in [8].
II: Item generation and judgment	Create and refine items to be used in the instrument through expert judgment and think-aloud interviews.	Complete	Final list of items for validation study #1. Change in measurement scale. [9]
III: Validation study #1	Identifying the factor structure of the instrument.	Complete	Tentative factor structure for the instrument and removal of items for validation study #2.
IV: Validation study #2	Confirming the factor structure for the instrument.	Ongoing	Final factor structure for instrument.
V: Validation of instrument scores for fairness	Establishing guidelines for instrument scoring through measurement invariance tests and group comparisons.	Not started	Instrument scoring guide.

Using this data, we conducted an Exploratory Factor Analysis (EFA), which allowed us to identify potential factor structures for the items from Phase II. Our initial analyses included a scree plot and parallel analysis, which indicated that a structure of four or six factors could appropriately describe the data we had collected. Upon modeling the factor structure and performing subsequent analyses with the removal of items that showed low correlation, we were able to make informed judgments about the factor structure of the LMI. Through this process, we reflected on the theory we used to build the instrument, and the original 40 items measuring six learning constructs were reduced to 18 items measuring five learning constructs. Phase III also encompassed a preliminary demographic analysis, yielding valuable data on several key groups.

We also analyzed our data for demographic trends during Phase III. This analysis involved calculating several metrics for the dataset and each demographic group, including the mean, standard deviation, and skewness. The analysis of these demographic groups yielded some valuable preliminary insights that will guide further analysis and prospective survey groups. In general, men comprised about 75% of our sample, with the remaining 25% identifying as women, and a single non-binary participant. In terms of race and ethnicity, approximately 68% of our participants were White, 21%

Asian, 3% African American, 2% Latino, and the remaining 6% being multi-racial, Native Americans, Pacific Islanders, or Middle Eastern.

Within these responses, there appears to be little discrepancy in scores between men and women in the sample groups, and the sample size for non-binary respondents is too small to allow for any statistically significant inferences to be made. Furthermore, while there are some variations in mean scores between several racial/ethnic demographic groups, only two of these groups (White and Asian) have sufficiently large sample sizes, and the scores of these groups showed little variation from each other and from the overall sample. For example, in our five-point scale, White respondents had a mean of 3.82 (0.81) for the "Learning by Others" construct and a 3.71 (0.79) for the "Cultural Knowledge and Skills" construct, while Asian respondents had a mean of 3.72 (0.66) and 3.82 (0.62) for these same constructs, respectively. Table 2 shows how these two demographics scored in our instrument pilot.

Table 2

Mean scores for pilot survey by race demographic

Race	*n*	Learning by Doing	Learning by Others	Content Knowledge & Skills	Cultural Knowledge & Skills	Ingenuity
White	257	4.35 (0.64)	3.82 (0.81)	3.83 (0.88)	3.71 (0.79)	3.72 (0.78)
Asian	83	4.33 (0.52)	3.72 (0.66)	3.96 (0.69)	3.82 (0.62)	3.74 (0.72)
African American	11	–	–	–	–	–
Hispanic/Latino	7	–	–	–	–	–
Other	23	–	–	–	–	–

Table 3

Mean scores for pilot survey by makerspace use frequency

Makerspace Use Frequency	*n*	Learning by Doing	Learning by Others	Content Knowledge & Skills	Cultural Knowledge & Skills	Ingenuity
1x per Semester	23	4.03 (0.68)	3.62 (0.77)	3.36 (1.15)	3.53 (0.68)	3.41 (0.81)
2-3x per Semester	121	4.23 (0.65)	3.71 (0.80)	3.64 (0.90)	3.60 (0.73)	3.44 (0.82)
1x per Month	50	4.38 (0.60)	3.83 (0.79)	3.93 (0.85)	3.73 (0.79)	3.81 (0.67)
2-3x per Month	68	4.33 (0.68)	3.79 (0.87)	3.88 (0.74)	3.64 (0.75)	3.76 (0.65)
1x per Week	56	4.42 (0.43)	3.82 (0.66)	4.04 (0.64)	3.76 (0.56)	3.87 (0.68)
>1x per Week	57	4.52 (0.55)	4.11 (0.64)	4.20 (0.75)	4.10 (0.82)	4.14 (0.68)

However, there are several significant areas of note when analyzing students' makerspace use frequency (see Table 3). Students who reported using the makerspace the most frequently (responding that they use their makerspaces "more than once per week") had the highest mean scores across all constructs, and there appears to be a general positive correlation between makerspace use frequency and mean scores for each construct.

Current and future work

In the past year, we have completed Phase III and are now fully within Phase IV. This involves the collection of more survey data at other HEIs across the United States. The survey has been refined using the EFA from the third phase, and the refined survey has now been sent to multiple HEIs across the country. Using the data from Phase IV, we plan to perform a Confirmatory Factor Analysis (CFA) to validate the factor structure suggested by the EFA conducted within the third phase. We anticipate Phase IV to be completed by the end of Summer 2026, and once this is finalized, we will move to the final phase of the project. The fifth phase involves group comparisons and metric invariance analyses, which will enable the creation of an instrument scoring guide to assist with the interpretation of the LMI outputs within different populations.

Conclusions

In the past three years of this project, we have made significant progress towards our goal of producing a tool for measuring the effectiveness of learning processes and outcomes within makerspaces at HEIs. Within this time, we have developed a set of constructs to measure students' abilities to learn within makerspaces. After their development, we have utilized think-aloud interviews, discussions with professionals, and mathematical analysis of sample data to further refine these constructs.

More recently, we conducted our first validation study, through which we refined the LMI by better aligning our items and constructs with the observed data. Additionally, through demographic analysis of the same data used in the validation study, we have been able to make some preliminary group comparisons and identify similarities between White and Asian students.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant Nos. 2138352, 2138372, 2138447, and 2452322. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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