Board 243: Development and Validation of Learning Through Making Instrument (LMI) Project Overview

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Abstract: Makerspaces are increasingly more important in engineering education because they enable learner-guided experiences related to the process of creating. Many previous studies have investigated the nature of the learning that happens in makerspaces when students engage in the creative process, with factors such as makerspace culture, knowledge, and skills being examined. Currently, though, there are no instruments with evidence of validity and reliability for measuring the learning that happens within makerspaces. Therefore, in this project, we are aiming to create an instrument that can be used within diverse engineering education settings to help institutions assess the impact of makerspaces on their users. In previous NSF-funded projects, part of our team has been able to develop an intimate understanding of academic makerspaces through ethnographic methodologies, answering questions such as: who uses the spaces; how they operate; what users are learning; how users are learning. In order to move from qualitative findings into a quantitative instrument, we proposed this four-stage project along with experts in instrument development. The first stage is for developing construct definitions, where we determine what we want our instrument to measure by contrasting our team's expertise on makerspaces with the existing literature to create theory-informed definitions. From these definitions, we move onto the second stage, where we use those definitions to generate draft items to be used in the survey instrument. Those draft items then go through a review process with experts in both makerspaces and instrument design. Additionally, we recruit students in our target population to participate in think-aloud interviews: interviews where the students read through the instrument and talk out loud about their interpretation and thought process when answering the questions. The interviews allow us to assess if our target population is interpreting the items how we intended. The third stage is to design and conduct validation studies that will allow us to test our hypothesized factor structure and check for evidence of reliability of the instrument. Finally, the fourth stage consists of finalizing the instrument and conducting additional validation studies that examine how our instrument scores are related to fairness. In the end, the goal is to have an instrument that can be used in diverse engineering makerspace settings. At the present moment, we are in the second stage of our project, and we anticipate we will be on the third stage by the time of the conference.

Keywords: Makerspace; Assessment; Instrument development; Instrument validation

The maker movement has led to the creation of makerspaces as environments that allow users to engage in making endeavors. Although making can be defined in a multitude of ways, it is generally associated with the act of creating a physical or digital object through the strategic use of available resources within a supportive community [1], [2], [3]. Making has been increasingly associated with positive learning outcomes, including the promotion of disciplinary knowledge, attitudes, and professional skills [4], [5]. Because of the positive outcomes and the possibility of engaging students with the design process, makerspaces have attracted the attention of academic institutions, which have started creating such spaces on their campuses to serve engineering students and others interested [6].

While more and more academic institutions are using their resources to create and maintain makerspaces, it is difficult for those institutions to assess the impacts and outcomes of having those spaces–a goal that may be necessary for accreditation if the spaces serve co-curricular functions for academic programs. Existing studies point to a dramatic increase in the number of makerspaces worldwide over the last decade, with a particularly high number of those spaces concentrated in North America and Europe [7], [8]. Within the United States specifically, it was estimated in 2019 that around 41% of state higher education institutions had or were interested in having a makerspace [9]. When used for educational purposes, makerspaces need to enable learning experiences for their users, which might be facilitated or hampered by certain approaches [6]. There are currently no valid and reliable assessment instruments that academic institutions can use in order to measure the learning that students experience in makerspaces. The lack of such a validated instrument limits institutions' abilities to understand and improve on the impact their makerspaces have on students.

Our research project was proposed with the goal of creating an assessment instrument that can fill this gap for higher education institutions, allowing the measurement of learning in makerspaces for a specific makerspace or multi-institutional projects and with diverse student populations. The overarching research goal for our project is "To develop a reliable and valid survey instrument to obtain measures of student learning in makerspaces which can measure how pervasive engineering student learning is in makerspaces." To accomplish our goal, we selected a solid theoretical foundation for our work: the Learning Through Making Typology [10]. We selected the typology because (a) it summarizes the expertise of part of our research team, which participated in the research and development of the typology; (b) it was developed through extensive qualitative work where the researchers investigated real makerspace users in academic settings through interviews and ethnographic methods; and (c) the researchers wanted to highlight the experience of minoritized populations in makerspaces, thus they developed the typology through a research design that sought to give a voice to women in these environments.

Project phases

Our project is organized over five phases that will allow for the development of an instrument with evidence of validity, reliability, and fairness. The different phases, along with their associated activities and research questions, are outlined in Table 1. Our procedure generally follows the one proposed by Netemeyer et al. [11], which includes (a) defining the domain and the constructs to be assessed; (b) creating preliminary items and refining them through feedback from experts and potential users of the instrument; (c) conduct quantitative studies to define and refine the scale; and (d) conduct additional validity studies to finalize the scale and understand the impacts of the assessment.

The first phase is Construct Theory and Definition. The goal of this phase is to create definitions supported by existing literature for the constructs that we intend to measure with our instrument. Although we started our project with the Learning Through Making Typology as our foundation, we are aware that the typology represents the experience of a limited sample of academic makerspace users. It is, therefore, necessary for us to engage in conversations that would allow us to understand the core idea of each of the Typology's constructs. After forming that understanding, we will review existing literature on makerspaces and tangential topics to help us create construct definitions that reflect more than just our own perspectives on makerspaces. The purpose of these definitions is to guide the creation of survey items and interpret the results of these items as they coalesce into factors.

The second phase of our project, Item Generation and Judging, is focused on writing and revising survey items with different sources of feedback. First, taking the construct definitions generated in the previous phase, we will create a set of survey items associated with each of the constructs we wish to measure. Second, we will ask experts in makerspaces and experts in instrument development to review our preliminary items in terms of their alignment with the constructs and their writing. With the expert feedback in hand, we set out to revise our items to better reflect the constructs we intend to measure.

Next, we will recruit a diverse pool of students from three different institutions in order to conduct cognitive (think-aloud) interviews about the current version of the survey. In these cognitive interviews, our objective is to understand how students in our target population are interpreting the items we created so we can ensure that our respondents will answer the items in the way we anticipate. As a result of these cognitive interviews, our survey items may undergo additional revisions.

With a first version of the survey complete, we will move on to the third phase of our study: Validation study #1 of factor structure. In this phase, we will deploy the existing version of the survey to participants who are students at one of at least three different institutions to collect preliminary data for statistical analyses. In order to ensure high-quality data points and an appropriate number of responses, we will be offering compensation to the students who complete our survey. With a sample of around 400 responses, we will conduct an Exploratory Factor Analysis (EFA) to assess the factor structure of our data and compare that to the theoretical structure we had created. Those results will inform potential changes to the instrument, such as the elimination or rearrangement of items.

Once we settle on a factor structure that represents our initial data set and aligns well with the theoretical foundation for the instrument, we will proceed to the fourth phase of the study, which is a second validation study of the factor structure. Using a different data set, the new validation study will focus on assessing the factor structure from the previous step through Confirmatory Factor Analysis (CFA). More specifically, the CFA will show us how well our data is represented by the factor structure we have for our instrument. The different CFA models will be compared through fit indices—including absolute, comparative, and parsimony indices—which will then be used to support our selection of a final model.

Table 1: Phases of the project and corresponding research questions and activities.

Phase	Activities	Research questions
I: Construct theory and definition	Creating definitions for the constructs to be measured through literature review and discussions about the Learning Through Making Typology.	No RQs answered in this phase.
II: Item generation and judging	Development of preliminary survey items. Expert reviews of alignment between construct definitions and survey items.	RQ1: To what extent are measurement construct specifications and actual assessment questions aligned?
	Cognitive interviews with students in our target population. Revisions of survey items.	RQ2: To what extent do a diverse group of students who will potentially use makerspaces cognitively understand the items as intended?
III: Validation study #1 of factor structure	Deployment of first version of the survey. Exploratory Factor Analysis.	RQ3: To what extent are items written to capture a single construct?
		RQ4: To what extent does the data-driven factor structure align with the theoretical framework?
IV: Validation study #2 of factor structure	New round of data collection. Confirmatory Factor Analysis.	RQ5: To what extent does the conceptual framework explain the patterns in the data?
V: Validation study of instrument scores to evaluate fairness	Measurement invariance tests.	RQ6: To what extent are there measurement invariances between gender & minority groups?
	Mean group score analysis. Development of scoring guide for the instrument.	RQ7: Are there significant differences in the mean scores between groups that indicate certain groups are learning differently in makerspaces?

Finally, the fifth and last phase of our project will be a final validation study focused on the fairness aspect of our instrument. This fairness study will be necessary in order to establish how well our instrument applies to different groups of interest within our population, ensuring that the instrument is robust enough to support appropriate conclusions for them. Additionally, we will also check for differences in mean scores for these different groups. We will accomplish these goals by testing for metric invariance and comparing mean scores through methods appropriate for our data (e.g., ANOVA, t-test, or non-parametric equivalents). The groups will be selected to support fairness of the instrument across gender and underrepresented learners.

Current results

As of the writing of this paper, our team has completed Phase I and is currently analyzing the expert feedback in Phase II. Therefore, our most significant results so far are the preliminary structure and construct definitions we generated in Phase I, which are represented in Table 2. The constructs were derived from the Learning Through Making Typology, and the categories in Table 2 indicate the broader group that encompasses the constructs. We generated a total of 45 items that were sent to the experts for their judgment, and we got responses from 25 experts.

Implications and future steps

The results of Phase I are our finalized construct definitions for the aspects of learning in makerspaces, which are outlined in Table 2. These results pave the way for the construction of a first iteration of our survey as they include the definitions representing a comprehensive understanding of the learning that happens in makerspaces. Each of the definitions was carefully crafted through discussions and a review of the literature—which resulted in definitions that should represent the knowledge of the makerspace community more broadly. Although there might be other aspects related to makerspaces of importance for other researchers, we believe that this set of definitions can provide the community with an important starting point for investigations of specific aspects of learning or that examine the process as a whole.

In terms of future work, we will finish conducting our think-aloud interviews and strategically revise our survey items in order to finish Phase II of our project. We anticipate that, upon its conclusion, the project will have meaningful impacts in academic makerspaces and enable an entirely new direction of research within this space. Our finalized instrument should be applicable to makerspaces in diverse settings and allow core aspects of the learning process to be quantified. Such quantification will grant researchers the ability to investigate the effects of specific interventions or designs for makerspace activities, ultimately adding to the impacts of having makerspaces in higher education institutions.

Table 2: Construct definitions created during Phase I of the project.

Category	Construct	Definition
Mode of learning	Learn by doing	The process of active learning guided by students' projects within a space that promotes and supports authentic and exploratory making experiences in which students strategize, fail, reflect, and succeed in realizing their ideas [4], [12], [13], [14], [15], [16], [17].
	Learn by others	The process of learning through observation, co-presence, or communicative sharing of inspiration, know-how, ideas, and designs through relationships in the maker community [2], [18], [19], [20].
Product of learning	Content knowledge and skills	Students' internalization of making operational skills and techniques through engagement in the makerspace, which informs technical knowledge and experience [14], [21], [22], [23], [24].
	Cultural knowledge and skills	Students' learning, translation, and negotiation of the implicit and explicit rules, conventions, and identity-related expectations within a dynamic makerspace community [25], [26], [27], [28], [29].
	Ingenuity	The practices used to innovate solutions shaped by the constraints of the makerspace and students' social relationships [30], [31], [32], [33].
	Self-awareness	Students' reflection on their identity and their personal growth in attitudes, motivation, and character through engagement in the makerspace community [32], [34], [35], [36], [37].

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