Where Be Dragons? Charting the Known (and Not So Known) Areas of Research on Academic Makerspaces

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Leah F. Rosenbaum[1] and Björn Hartmann[2]
[1]Graduate School of Education, University of California, Berkeley; e-mail: leahr@berkeley.edu
[2]Jacobs Institute for Design Innovation, University of California, Berkeley; e-mail: bjoern@berkeley.edu

INTRODUCTION

As the Maker movement has grown in general popularity during the last decade and a half, so too have Making and Makerspaces garnered increased recognition within education[1]. Accordingly, the field of research on the role of Making within education has similarly expanded.

This paper presents a survey of research on Making in education. The goal of this summary is to first map out the larger landscape of research on Making and to then specifically situate research on undergraduate work in academic Makerspaces within that landscape. While other researchers [16, 64] present more comprehensive literature reviews, they do not focus on undergraduate Making. Certain areas within this map have been extensively documented while others call for more thorough investigation and research. In particular, the literature is rich with work describing the design, founding, and facilitation of Makerspaces on college campuses. However, data-driven studies of student experiences within those spaces, as well as consideration of student populations beyond engineering majors, are rare and present opportunities for valuable and fruitful future research.

SAMPLING PROCEDURE

In compiling this literature review, the authors reviewed approximately 70 papers. These papers were located through Google Scholar searches employing terms such as "undergraduate Making," "college Makerspaces," and "Making in education." These papers were peer-reviewed, whenever possible, and published at well-known conferences and journals in their respective fields. For each paper, researchers reviewed the abstract, research questions, and methods to ascertain the paper's primary research space and approach. References were also mined to locate additional relevant papers. When reference mining yielded only already-reviewed papers or more papers within the same primary research space, researchers deemed that space saturated for our review purposes and continued on to other topics.

MAPPING RESEARCH COMMUNITIES

The growing field of research on Making in education overlaps with research on Making generally [20] and often brings in concerns and methodologies of pre-existing research communities (see Fig. 1). It spans a wide range of topics, such as the potential benefits of Maker practices as learning resources [36]; the tensions between Making practice and traditional education pedagogy [16]; the processes and experiences of learning within Makerspaces [60]; even reflective meta-research on popular technologies, subject areas, and metrics used in research on the Maker movement [44].

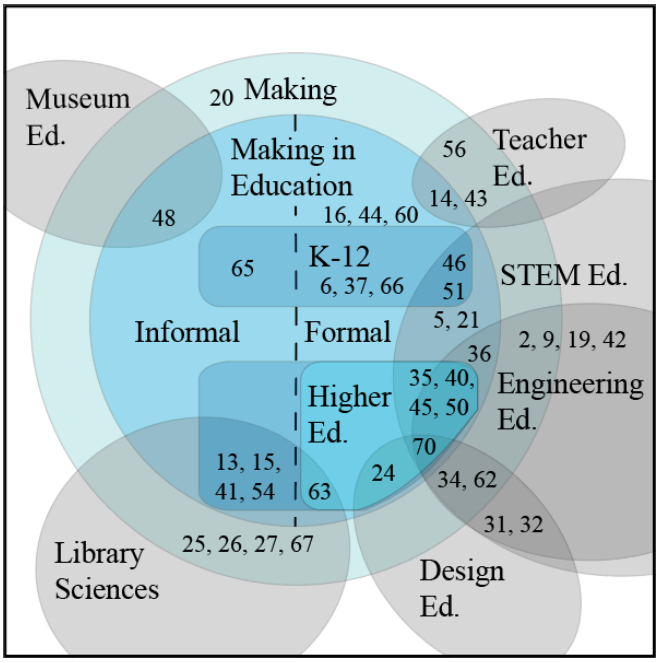

Fig. 1. Overlapping fields of research comprise the literature on Making in education. Numbers in this figure correspond to cited references.

A. INFORMAL AND FORMAL SPACES

Broadly, the literature on Making in education is divided between informal and formal spaces. From its roots in extracurricular spaces, Making continues to thrive in informal learning environments such as museums, hobby clubs, after-school programs, summer camps, and community-based Makerspaces. Many research agendas focus on these contexts [for example, 65], and a multitude of articles, chapters, and books outline and study the educational opportunities of informal Making both for children [48, 65] and adults [20].

In the last decade and a half, Making has also moved into formal education spaces, both K-12 schools and college campuses [16]. Numerous practical guides provide

[1] Some researchers situate the roots of Making in education back to Seymour Papert's seminal works on constructionism in the 1960s and 1970s [37, 16]. Others trace them back further to progressive educators of the early 20th century [57]. Nevertheless, the emergence of Making, as formally named, in education is largely a 21st century phenomenon.

pedagogical tenets, design heuristics, and activity suggestions for parents, educators, and community stakeholders to bring Maker practices into their schools and classrooms [6, 37].

B. LIBRARY MAKERSPACES

Libraries emerged as a prominent link between Making in informal and formal contexts. In addition to providing text and media resources, many community-based and academic libraries also provide patrons, including university students, faculty, and staff, with digital tools and fabrication technologies. In their programming, library-based Makerspaces tend to foster informal use, often facilitated through workshop events [54, 15] rather than through full-length courses.

Library science journals frequently include guides for establishing library-based Makerspaces [25, 27, 26] as well as implementation reports [13, 15, 54]. Some of this work quantifies usage patterns [54] while other work qualitatively assess the impact of library-based Makerspaces on individual users and the broader community [41]. Comprehensive literature reviews also report on Makerspaces in libraries generally [67] and in academic libraries specifically [63].

C. MAKING AND DOMAIN-SPECIFIC EDUCATION

At all levels of formal education, various research programs study Making as a resource for domain-specific learning. Most common are links to various STEM domains of science [21, 51], technology [5], engineering [36], and mathematics [46, 22, 21] as well as to design education [24, 31], which will be further discussed below. For example, Making has been positioned as a resource to engage students in cycles of inquiry and exploration to access scientific concepts and relationships, contrasting traditional fact- and memorization-based approaches [51]. Other researchers and educators position Making as providing resources for social justice actions [66] and even as a tool for teacher education for both pre-service [14] and in-service teachers [43, 56].

D. MAKING IN UNDERGRADUATE ENGINEERING

Within the literature on undergraduate education, Making is most often positioned as a resource for engineering students. At a high level, some researchers consider the role of laboratory work in engineering education [9]. Others trace a historic decline in work study practices, including prototyping and fabricating methods, and outline the merits of its reintroduction [2, 5]. Still other researchers outline ways in which Making can link engineering skills to tenets of liberal arts education such as "critical social inquiry and humanistic educational frameworks" [40].

Taking a more ground-level approach, some educators report on efforts to integrate Making into undergraduate courses, proposing guidelines and heuristics for such work [70, 35, 24]. Other researchers take an even finer-grained approach, evaluating the cognitive processes at play as their engineering students learn to use new tools and technologies [50, 45].

All the enthusiasm around Making and engineering can blur the distinctions between them; these distinctions themselves are the topic of research [19, 42].

E. DESIGN THINKING

After engineering, design is the second most common discipline associated with Making at the undergraduate level, at times overlapping with engineering education (Fig. 1). Design researchers tend to emphasize Making skills such as ideating, prototyping, and studio methods, though typically in a technology-agnostic fashion rather than in a formal Makerspace. Some of this work focuses on curriculum development, such as sharing how studio methods [34] or design thinking [62] can be integrated into undergraduate engineering coursework and with what impact. Other work defines particular skills, such as prototyping [32], and seeks to develop "an assessment framework for design learning" [31]. Implications of this work apply broadly to learning through Making, whether it occurs in a formal Makerspace or not.

So far, this review has briefly established the different academic disciplines and communities that contribute to research on Making in education, including in K-12 settings. We then reviewed work on undergraduate Making, but have thus far discussed undergraduate Making agnostic to the setting, that is, independent of designated Makerspaces. The remainder of this review focuses on research conducted in Makerspaces located at institutions of higher learning, so-called *academic Makerspaces.*

RESEARCH ON ACADEMIC MAKERSPACES

While high tech tools and precision fabrication techniques have long had a place on college campuses, they were often tucked away in specialized laboratories, available to only a few students and limited to formal research projects.

Table 1. Reports on academic Makerspaces

Area	Authors	Paper	Target Area				
			Equipment /Space	Admini-strators	Staff	Student Users	Course
Program Implementation Reports	Blacklock & Claussen (2016)	[4]	x				
	Forest, et al (2014)	[11]	x			x	
	George-Williams (2015)	[13]	x		x		
	Guek (2015)	[15]	x				
	Lagoudas, et al (2016)*	[29]	x			x	
	Lamancusa, et al (1997)	[30]	x				
	Pines, et al (2015)*	[49]	x			x	
	Rees, et al (2015)	[52]	x				x
	Rogers, et al (2015)*	[54]	x			x	
	Spencer et al (2016)	[61]	x			x	
	Wilczynski, et al (2014)*	[69]	x				
Comparisons across Makerspaces	Barrett, et al (2015)	[3]	x				
	Forest, et al (2016)	[10]	x				
	Galaleldin, et al (2016)*	[12]	x				
	Wilczynski (2015)	[67]	x		x		
	Wong & Partidge (2016)	[70]	x		x		
Curriculum Development	El-Zanfaly & Knight (2016)	[8]				x	
	Pappas & Prins (2010)	[45]	x				x
	Kim & Rutgers (2016)	[24]					x
	Malicky, et al 2010*	[35]					
	Nieusma & Malazita (2016)	[40]					x
	Wilczynski, et al (2016)	[70]	x		x		x

Table 2. Empirical studies on academic Makerspaces

Area	Authors	Paper	Methods		Sample Size	Outcomes Measured		Curricular Integration				Non-Engineering Disciplines Engaged
			Quantitative	Qualitative		Engineering Skills	Perceptions/ Experiences	Extra-curricular	Activity-level	Course Curriculum	Undergrad. Trajectory	
Evaluating Activities	Malicky, et al (2010)*	[35]	survey		4 activities	x			x	x		
	Prins & Pappas (2010)	[50]	survey		4 activities	x	x		x	x	x	
Impact on Attitudes and Competencies	Galaleldin, et al (2016)*	[12]	survey		30	x	x				x	
	Kusano & Johri (2014)	[28]		grounded theory	10		x	x				Student groups
	Lagoudas et al (2016)*	[29]	survey		123	x	x					
	Morocz, et al. (2016)	[39]	survey		518	x	x				x	
	Wilczynski, et al (2014)*	[69]	instructor assessment		not specified	x				x	x	
Understanding User Experience	Harnett, et al (2014)	[17]		ethnography	9	x	x			x		
	Kayler, et al (2013)	[23]		qualitative coding	16		x			x		Library; Unaffliiated
	O'Connell (2015)	[41]		case study	5		x	x				Librarian, IT staff
	Penny, et al (2016)	[47]		ethnography	not specified		x					
Use Patterns	Pines, et al (2015)*	[49]	survey		250							
	Rogers, et al (2015)*	[54]	survey; checkouts		10; 627			x		x		

Academic Makerspaces not only open these tools and technologies to wider campus college communities; they also provide curricular and extra-curricular programming and support the communities of users that arise from these activities.

Broadly, the literature on academic Makerspaces can be divided between reports (Table 1) and empirical studies (Table 2). Reports share work done in support of academic Makerspaces – such as space design, staffing models, or training programs – but don't primarily focus on data collection and analysis (Table 1). Some reports mention existing or planned empirical work but do not present data or substantive analysis thereof. Data-focused empirical studies, on the other hand, were those that presented data, either in figures, tables, quotations, or some other format, along with analysis of that data (Table 2). Papers that include reports and substantial empirical work are included in both Tables 1 and 2 and are marked with an asterisk.

Several themes emerged within reports on academic Makerspaces. Program implementation reports, in which authors share physical layout, equipment lists, and facilitation practices, were common [4, 11, 13, 15, 29, 30, 49, 52, 54, 61, 69]. Additionally, numerous comparative studies highlight trends in equipment, usage, and facilitation across sampled academic Makerspaces [3, 10, 12, 68, 71]. A third common area of publication is curriculum development, that is, sharing particular activities, facilitation techniques, or course curricula to use in Maker-based courses [8, 24, 40, 45, 70].

Empirical studies tended to focus less on the physical spaces themselves and more on student experiences within those spaces. Such work includes studies on the impact of Makerspace participation on students' engineering and design competencies [12, 29, 69], autonomy [28], self-efficacy [39], and engagement [49, 54]. While most of these studies employ quantitative methods, some ethnographic work has been done to deeply understand student experiences within Makerspaces [17, 23, 41, 47]. Key findings from this qualitative work include the merits of ill-structured environments as places for student growth [17], the complexities of embracing failure as part of the learning process [23], and the obstacles students face –whether physical or socio-emotional – to entering an academic Makerspaces and becoming part of its community [47].

These general trends in academic Makerspace research also apply to ISAM 2016 proceedings, which include program implementation reports [33, 53, 59], cross-space comparisons [1], and curriculum development [8]. These proceedings also reflect the trend across Maker research generally to include library resources [55]. Due to shorter nature of ISAM papers, these publications tend not to go into the same depth as full-length journal articles.

DISCUSSION

A. LACK OF DATA-DRIVEN RESEARCH

Overall, in-depth, data-driven research on academic Makerspaces was scarce. Only 13 empirical studies on academic Makerspaces could be located for this review,[2] and of those, 6 were presented as part of program implementation or curriculum development reports. Given that Makerspaces, at least by name, are relatively recent additions to most college campuses, it is understandable that existing literature focuses primarily on logistics of implementing and running these spaces. While this

[2] Some program implementation reports [for example, 4] mentioned planned or in-progress data collection and analysis efforts. Reports on those full studies could not be located at the time of this paper.

information is valuable for establishing such spaces, it does not represent robust empirical research, nor does it contribute to understanding student experiences or learning. The results of this review support what others [18] have recommended, namely that research in academic Makerspaces should expand to include data-driven efforts and should seek to understand, theorize, and improve student experiences within those spaces.

B. ENGINEERS ONLY

The topics addressed by the existing empirical work also point to new areas for research. Almost all reviewed empirical studies focus on engineering students and engineering skills. Given that Making can support learning across a range of disciplines [see 21, 46, 51, 66], it could be useful to know how work in academic Makerspaces supports students in domains other than engineering. Even for declared engineering students, Maker-based courses could be among the more interdisciplinary courses they take. In what ways do these courses differ from traditional engineering courses, particularly in the attitudes and sensitivities they foster? Working to answer these questions could help substantiate claims about the benefits of Making for undergraduates.

C. NARROW CURRICULAR FOCUS

Additionally, most reviewed studies either focused exclusively on formal coursework or failed to distinguish between formal and informal Making. Exceptions include Kusano and Johri [28], who evaluate engineering students' extracurricular Maker experiences, and Harnett et al. [17], who studied a cooperative learning program with a local, community-based Makerspace. Overall, however, extra-curricular Making seems understudied given its prevalence on many college campuses, often within the same academic Makerspaces that host formal coursework. Studies sensitive to work in informal student clubs and workshops could better capture the range of Making activities that take place on college campuses and the communities that emerge from them. Such work could also help strengthen formal course offerings by borrowing best practices from informal Making.

D. LIMITED METHODOLOGICAL DIVERSITY

Finally, research on academic Makerspaces would benefit from greater methodological diversity. All but one of the reviewed quantitative studies employed self-report survey methods, often without a pre/post comparison or statistical analysis. A greater range of more sensitive quantitative methods is needed to evaluate the impact of academic Makerspaces. Quasi-experimental research design [58] could be particularly appropriate given the range of pre-existing variables (class composition, different instructors, difficulty of a true control group) in most academic Makerspaces. Careful experimental design, plus sound statistical analysis, would increase the rigor of quantitative research in academic Makerspaces. We also see opportunity for additional qualitative work. The 5 reviewed qualitative studies use a range of methodologies, including case study, ethnography, and grounded theory[3], to characterize student experiences in academic Makerspaces. As this field continues to grow, these diverse qualitative methods will prove useful in characterizing the range of experiences and perspectives that arise through academic Making.

CONCLUSIONS

As Making has gained popularity in mainstream culture and in K-12 education, so academic Makerspaces have begun to proliferate on college campuses around the world. Accordingly, the field of research on academic Makerspaces has also started to grow. This literature review contextualized research on academic Making within research on Making in education generally. Related areas included informal learning, especially in libraries, as well as formal, domain-specific education research, primarily in STEM fields and design. While the field's growth is encouraging, this review also highlighted key under-explored areas of the literature on academic Makerspaces. Data-driven empirical studies emerged as a rarity, as did work on academic Making outside the domain of engineering-specific skills. Despite their longstanding history on many college campuses, informal Making experiences were seldom the focus of empirical study, and quantitative research methods tended to be homogeneous. A wider range of data-driven empirical methods would enable researchers to more convincingly support claims about the benefits of Making in higher education.

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[3] For an introduction to qualitative methodologies, see [7, 38].

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