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Identifying and Sharing Best Practices in International Higher Education Makerspaces

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Malcolm Cooke has over 35 years' combined experience in academia both in England and for the last 21 years in the US. For most of this time he has focused on design, and advanced manufacturing, and for the last 25 years his manufacturing focus has been in the growing field of additive manufacturing.

Malcolm received his Bachelor of Engineering degree from Coventry University, his Master of Science degree from Warwick University, both located in England, and his Ph.D. (2004) from Case Western Reserve University (CWRU) in Cleveland, Ohio. Malcolm has been a faculty member at CWRU for 16 years.

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Malcolm's research interests are focused on applying additive manufacturing technologies to address biomedical challenges, and in particular the design and manufacture of biocompatible, biodegradable implantable porous scaffolds for the repair of hard and soft tissue defects. Also Malcolm collaborates with local surgeons to provide 3D printed anatomical models from patient CT and MRI data that are used for resident training, patient communication and research-based surgical planning.

Identifying and Sharing Best Practices in International Higher Education Makerspaces

Academic makerspaces are being added to college and university campuses around the world. While this trend began in the United States, it has rapidly spread internationally with a growing number of higher education institutions adding these facilities to create communities where participants learn, fabricate, and share knowledge. As more institutions add these spaces to their infrastructure, there is a greater need to identify and share best practices in this growing field of engineering education. As one example, the 1st International Symposium on Academic Makerspaces was held in Cambridge, Massachusetts in November, 2016 and drew 300 participants from 115 universities, 20 companies, and 6 continents. The symposium included 19 sessions of papers and workshops with presenters from Austria, Brazil, Bolivia, China, Canada, Guatemala, New Zealand, Pakistan, Peru, South Korea, and the United States. This paper details the history of the collaboration that created and delivered this inaugural symposium. In this paper, the symposium's international papers are reviewed to identify common practices in, and challenges for, international academic makerspace. Finally, additional plans to share best practices in international higher education makerspaces are presented.

Introduction: Identifying and Sharing Makespace Best Practices

Higher education is in the midst of a trend that is having a major impact on engineering education. Colleges, institutes, and universities are creating new locations for students, faculty, and staff to come together to learn, create, and fabricate. Referred to as higher education makerspaces and academic makerspaces, these facilities have been established at many institutions. This trend has been prompted by developments in several areas, including calls from industry for more practical skills in engineering graduates as well as increased access to and support for digital manufacturing [1, 2].

Higher education makerspaces combine elements of traditional machine shops (such as hand tools, portable power tools, and standing machinery) with modern tools for design and fabrication (such as computer aided design software and laser cutters). In addition to the tools and equipment, higher education makerspaces also promote collaboration and peer-to-peer learning. These elements help develop a sense of community and individual ownership in the space. Support staff are another essential component of higher education makerspaces to provide the needed training and oversight within the spaces.

There is no single model of what constitutes an academic makerspace, with each institution providing the resources and structure that best meets their needs for design-centered functions. For example, some spaces are student-managed while others have a professional staff to direct operations. Learning in such spaces occurs in many ways, ranging from structured classes taught by faculty members to equipment instruction delivered by the makerspace staff. Some makerspaces host academic courses within the space where faculty members teach theory and apply knowledge using design and fabrication skills. The use of each space is unique to each institution, with spaces typically supporting curricular, extra-curricular, personal, and entrepreneurial projects.

It is noted that engineering programs have always included elements of higher education makerspaces in their programs but these elements were often regarded as individual parts rather than as a collective whole. For example, machine shops were (and many still are) viewed as independent operations that service courses and research endeavors. Similarly, undergraduate teaching labs, such as those that might support a mechatronics course, were (and sometimes still are) treated as single-purpose resources for experiments and projects related to that course. Makerspaces are unique from these examples in that they are a collection of many elements and frequently operate on an open use principle. These approaches help create communities that focus on discovery, design, and collaboration.

The academic makerspace concept is not limited to engineering programs but rather extends across the college campus. The diversity of users, ranging from engineers to artists to economists, produces a rich pool of talent that can lead to creative solutions. Given their historical roots of machine shops and engineering design projects, many institutions base their makerspaces within engineering programs, but make the facilities open to the entire campus community. There are also a growing number of liberal arts institutions that are creating makerspaces, as well as a movement by university (and community) libraries to create makerspaces within their facilities.

While acknowledging that each space is unique and was created to meet a (local) institutional purpose, there are many common aspects of academic makerspaces. For example, fostering community, ensuring safety, selecting equipment, providing training, managing operations, and administering finances are central activities for all makerspaces. During the last ten years, as higher education makerspaces have come into existence, academics have shared academic makerspace experiences in conferences, proceedings, and journals organized by engineering education and professional societies. A set of higher education makerspace best practices has developed from these efforts, but the lack of a coordinating organization has slowed the distribution and adoption of such findings. In 2016, the 1st International Symposium on Higher Education Makerspaces was organized to collect and disseminate best practices for academic makerspaces.

International Symposium of Academic Makerspaces: History

Individuals from 8 institutions self-organized to collaborate on a series of events that ultimately created the International Symposium on Academic Makerspaces. The founding institutions were Carnegie Mellon University, Case Western University, Georgia Institute of Technology, Olin College, Massachusetts Institute of Technology, Stanford University, University of California, Berkeley, and Yale University. Each institution had one or more active makerspaces, though each program was unique in its purpose and organization.

Professor Martin Culpepper - MIT's Maker Czar - organized an initial meeting of these institutions to share lessons learned and promote collaboration. The meeting led to the development of a three-day workshop for universities that were planning to create an academic makerspace. The workshop "*Creating and Maintaining Safe and Productive Makerspaces that Matter to Students*" was hosted at MIT and taught by members of the makerspace collaborative. Approximately 50 individuals, representing 30 institutions and 5 countries, attended this workshop. The workshop included sessions devoted to the community and culture of makerspaces, staffing models, space definition and equipment layout, safety considerations, navigating campus politics, programming activities, collecting data, establishing performance metrics, and financing makerspace operations.

Typical equipment found in makerspaces was also presented at the workshop along with tours of a variety of MIT makerspaces. Examples of a range of makerspace types, spanning student-led activities to university-initiated spaces, were shared, with the organizing institutions' makerspaces used as references. The workshop emphasized the community and cultural aspects of higher education makerspaces and stressed that establishing these aspects is critical to the success of each makerspace. These principles, coupled with the concepts of openness and collaboration, were presented as key components that define an academic makerspace and differentiate academic makerspaces from traditional machine shops, labs, and other cooperative learning spaces.

Reflecting these academic makerspace attributes, the workshop was structured with an open and collaborative framework. For example, case studies not only shared successes but also included examples of less than fully successful endeavors. Much like the community within a makerspace, the workshop participants and instructors bonded as a large group, sharing insights individually and collectively. The gathering led to a number of site visits by attendees to the instructors' home campuses. As another example of the workshop's collaborative structure, attendees were provided with workshop presentations, thereby equipping the participants to easily share information at their own institutions following the workshop.

The workshop, which was repeated 5 months later for a new group of attendees, served as an organizational and programming catalyst for the founding collaborators. The makerspace planning and operations workshops were well-received by the attendees, with requests for additional information and increased collaboration among makerspace advocates. These calls for action ultimately led to the 1st International Symposium on Academic Makerspaces (ISAM). An organizing structure called the Higher Education Makerspace Initiative (HEMI) was created to organize the symposium and plan activities that promote makerspace collaboration [3]. The 8 founding institutions became the inaugural members of this new organization.

International Symposium of Academic Makerspaces: Purpose & Format

ISAM was created to link individuals involved in higher education makerspace initiatives and to establish a forum for exchanging knowledge in this developing field. The symposium was structured to be equal parts information exchange, discussion, networking, and experiential. A global audience of faculty, higher education administrators, educational researchers, students, makerspace managers, and practitioners was envisioned as participants in the event. Regarding practitioners, that group included equipment manufacturers, architects, non-academic making enthusiasts, and leaders from government and non-profit organizations.

A goal of the symposium was to distribute information and facilitate idea exchanges that could broadly infuse makerspaces into higher education. Noting that the value of higher education makerspaces extends across campuses, the symposium included the participation of representatives from a diverse collection of programs including music, entrepreneurship, medicine, architecture, mathematics, and the liberal arts. The symposium's sessions were selected to cover a range of topics that could benefit new and existing programs housed in engineering and other schools. The symposium recognized the role of makerspaces as catalysts for fostering interdisciplinary interactions and as a unifying force to support peer communities that extend beyond the boundaries of a makerspace.

Fundamental to the symposium was an understanding that there is not a preferred structure for all higher education makerspaces, but rather that each institution must develop its own best model. The symposium provided a format to share knowledge, including anecdotes and measurable impacts, related to the community, culture, training, safety, equipment, programming, funding, and data collection associated with higher education makerspaces. Tours of MIT's makerspaces were included and allowed attendees to make their own observations of equipment, layout, use, operations, and safety standards.

A variety of formats allowed participants to also learn from other attendees at the symposium. Short courses on the principles of and practices within higher education makerspaces provided participants with an overview of this field and training in fundamental makerspace equipment. Experts were invited to share insights on research and emerging areas in higher education makerspaces. Technical papers and poster sessions disseminated recent advances in the field, with each session followed by a community discussion on core topics and new developments. Vendors of makerspace equipment and sponsors of makerspace programs were also a component of the symposium with time provided to connect participants with the vendors. Equipment manufactures were invited to present technical papers and join panel discussions pertinent to their experiences. Students were essential contributors to the symposium where they participated in general sessions as well as sessions entirely devoted to student presentations. The schedule included networking opportunities and community building activities that allowed attendees to discuss ideas and engage with one another.

The call for participation in the symposium was distributed internationally with the assistance of the American Society for Engineering Education, the American Society of Mechanical Engineering, and other organizations. The response to the symposium was strong with the event reaching its maximum capacity. The symposium drew attendees from Austria, Brazil, Bolivia, China, Canada, Guatemala, New Zealand, Pakistan, Peru, South Korea, and the United States.

International Symposium of Academic Makerspaces: Results

The 1st International Symposium on Academic Makerspaces was held November 13-16 at the Massachusetts Institute of Technology and was attended by 300 people, with 52 papers presented in 18 sessions. The topics of each session are detailed in Table 1. Two evening poster sessions provided additional opportunities for the presenters to share their work with attendees. The organizers invited authors in key areas to present anchoring papers for specific sessions of the symposium. All papers were peer reviewed. In addition to the papers and poster presentations, the symposium included a collection of videos that showcased best practices at 8 institutions (including one high school that uses its makerspace to connect science, technology, and the arts). The papers and the presented slides were distributed to attendees and remain available for public access [4].

International Symposium on Academic Makerspaces: Session Topics	
Critical role of culture and community	Setting minimal boundaries and optimizing access
Makerspace programming and engaging your makers	Boundaries, culture, community and programming
Outreach to faculty, makers-to-be and URMs	Safety, regulatory and legal issues
Makerspace safety perspectives	Staffing models & characteristics of maker staffs
Examples of makerspace staffing	Makerspace management, budgeting, funding, tools and resources
Makerspace management examples	Metrics, data and measuring impact
Example of applying makerspace metrics, data, and information to make decisions	Campus collaborations and politics
Examples of campus collaborations	Makerspace import to entrepreneurship and innovation

Table 1. Session topics at the International Symposium on Academic Makerspaces

Presentations included discussions on start-up programs, makerspaces that are advancing from grassroots to institutionally showcased initiatives, institutional models for making, and campus-wide collaborations prompted by academic makerspaces [5, 6, 7, 8]. In addition to papers authored by engineering faculty, others were presented by safety experts, librarians, architects, and students. Faculty members from high schools, community colleges and universities participated in the symposium. Multiple papers addressed making and its role in college admissions, highlighting another key aspect of academic makerspaces.

The symposium included the following papers and presentations from institutions outside the United States:

- Best Practices for a Newly Established Academic Makerspace in a Nascent Maker Ecosystem (Pakistan)
- Using Makerspaces to Develop Didactic Models for Mechanical Engineering (Guatemala)
- Development of an Educational Program Using Capabilities of an Academic Makerspace (Austria)
- SNU Idea Factory with Integrative Approaches: From Physical Space, Education, to Culture (South Korea)
- Failure Modes of Academic Makerspaces (Bolivia, Brazil, Canada, and Peru)
- A Brief Introduction to China's Maker Movement and Makerspaces (China)

As reflected in these papers and the ensuing discussions, higher education makerspaces are having an impact on engineering education around the world. Establishing and sharing best practices for academic makerspaces is not only a national issue but is also an international opportunity to improve engineering education. A few themes were common to a number of papers and presentations at the International Symposium on Academic Makerspaces.

Community and culture are the most important attributes of higher education makerspaces. The originating workshops that led to the symposium emphasized these attributes and they resurfaced in the symposium as key elements that differentiate makerspaces from other design and fabrication facilities on college campuses. The community aspects of academic makerspaces help individuals feel welcome in the spaces and promote peer-to-peer instruction. With some spaces having over 1,000 active participants, it is essential that design assistance and fabrication instruction be widely available to the members.

A thriving makerspace culture is one where users of the facility share a sense of pride in ownership of the space. This culture is achieved through open access to the space (after sufficient training), having an openness of one's own work, and collaboration among users. A positive makerspace culture is evidenced by the users' respect and care for the space and its equipment, as well as community-wide support for safe operating practices. A positive makerspace culture is also an environment where makerspace managers, instructors, and members look out for and help one another.

Academic makerspaces need to be uniquely planned, developed, equipped, and managed to ***best serve the needs at each institution***. There is no "one size fits all" version of academic makerspaces. Similarly, there is not a standard list of equipment for all academic makerspaces, nor a standard guide for staffing these facilities. There are however many examples of best practices that can be incorporated into makerspaces, independent of the space itself. For example, concepts of safety and equipment maintenance (i.e. designating specific individuals to maintain specific equipment) are universal to all spaces. The absence of a singular model for academic makerspaces was emphasized in a number of the symposium's presentations and papers. One of the values of ISAM, as well as the growing body of knowledge on higher education makerspaces, is access to examples and case studies on academic makerspaces.

Makerspaces and their communities benefit by ***providing wide access***. That access may be to the space itself, welcoming users from all disciplines to the makerspace. A wide diversity of members can reduce barriers to problem-solving and create forums for multi-disciplinary collaborations. Also, each user has a unique set of skills, and makerspace access to a variety of users increases the talent pool within the facility. The concept of providing wide access can also apply to the use of the academic makerspace. Allowing the space to be used for curricular, extracurricular, and personal projects increases the value of the space to a larger number of individuals.

Wide access to training is another important component of higher education makerspaces. Using the undergraduate population as one example, 25% of the users in a higher education makerspace are new each year and require fundamental training. A widely accessible training platform, comprised of on-line, in-person, video, and text-based refresher guidelines can address a variety of user needs. Leveraging the knowledge in the community, it is suggested that vetted members of the makerspace community be utilized to train and oversee users in academic makerspaces.

The establishment of academic makerspaces on college campuses is shifting from a ***grassroots to mainstream*** process. Early proponents for academic makerspaces were individuals who saw the value in such spaces and predicted the benefits that could result. Those early adopters of the academic makerspace concept are now examples for other institutions to model their initiatives on. The creation of new academic makerspaces is now shifting from an individual (student or faculty member) initiative to an institutional initiative. Given this development, there is a growing need to inform others on best practices in academic makerspaces.

It is becoming popular, at some institutions, to ***affiliate innovation and entrepreneurship programs with academic makerspace activities***. Sometimes this association is promoted by existing entrepreneurship and innovation programs that need resources for product development. In other cases, academic makerspaces collaborate with innovation and entrepreneurial programs to assist makerspace users with their creative ventures. Such affiliations between innovation, entrepreneurship, and makerspace programs can benefit all elements of a university's organization. From a diversity perspective, it is imperative that the broad use of academic makerspaces be preserved, guarding against the sole use of these facilities as product development labs. As with all things, maintaining a sense of balance is essential to sustain the widespread value of makerspaces on college campuses.

International Symposium of Academic Makerspaces: Future Plans

A survey was sent to the 276 non-HEMI-affiliated attendees of the 1st International Symposium on Academic Makerspaces, with 42 attendees returning the survey. The survey included 12 questions, where 5 of the questions were open-ended and collected narrative responses. Some of the survey results are presented in Figure 1 (value of the symposium) and Figure 2 (conference attendees).

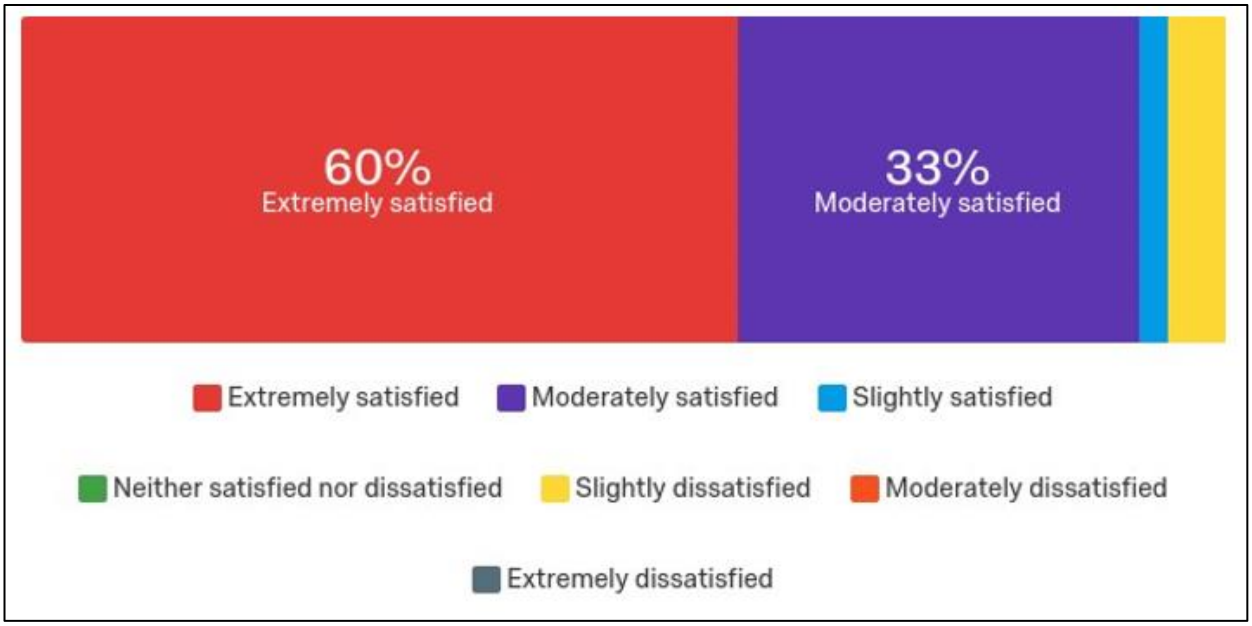

Figure 1. Responses to the question: "Overall, how satisfied or dissatisfied were you with ISAM 2016?"

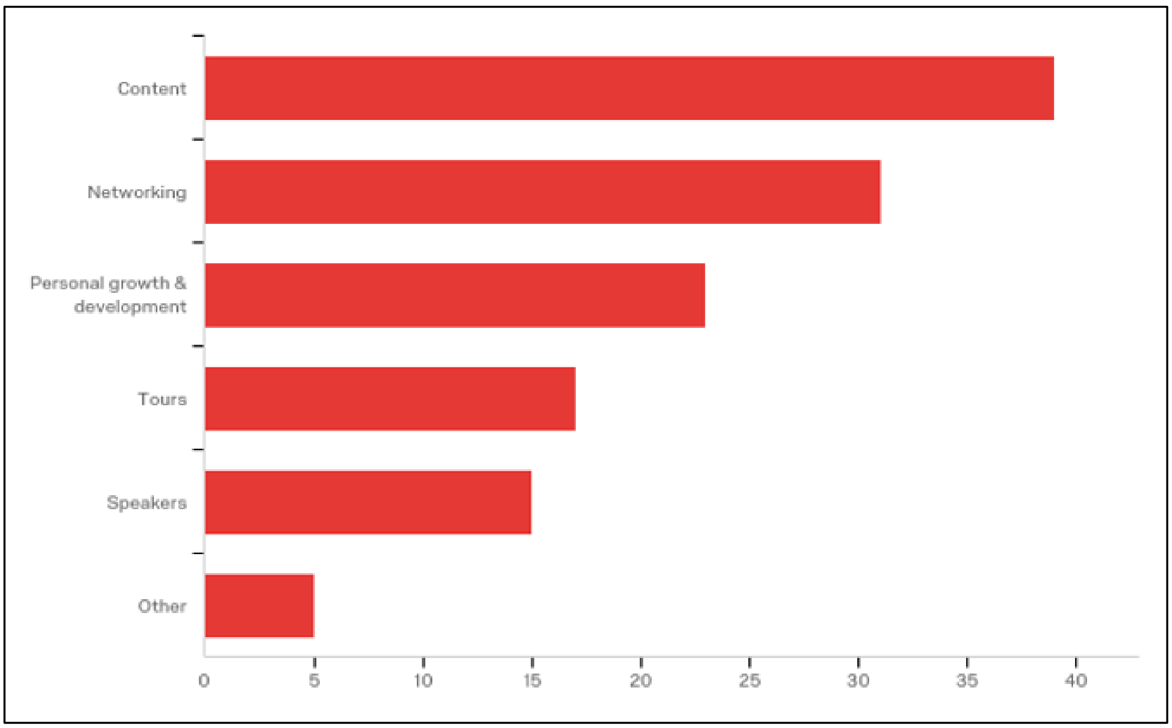

Figure 2. Histogram of response to the question: "What were your main reasons for attending ISAM 2016?"

As an example of open-ended questions, the survey explored the perceived value of the symposium and solicited information on additional workshops that should be included in the program. Another open-ended question on needed improvements identified the need for more time to allow attendees to interact with each other, a request for guides on specific aspects of managing makerspaces, and absence of diversity regarding the presenters. The survey results reflected the attendees' value of the symposium and provided support for annually hosting a conference on academic makerspaces. Partly motivated by the survey results, the 2017 International Symposium on Academic Makerspaces will be held in September, 2017 using a format similar to the inaugural event [9]. As with the original symposium, the international meeting will serve as a forum to discuss and share global best practices for academic makerspaces.

The Higher Education Makerspace Initiative is committed to creating accessible platforms to advance the state of academic makerspaces. As one means to accomplish this goal, the initiative created a web-based platform (Maker Share) to share best practices, resources, equipment reviews, and makerspace examples [10]. Like the open and collaborative nature of academic makerspaces, this web portal allows others to freely benefit from the collective wisdom of the academic makerspace community. This platform is in the public domain and serves as a widely accessible tool to share best practices.

In addition to the web-site, HEMI is also launching the *International Journal of Academic Makerspaces and Making* as a peer-reviewed publication of original papers on the impact of university makerspaces and making activities [11]. The journal will be offered on-line and share best practices in assessment, the use of data and metrics, culture and community, safety, recognizing and minimizing boundaries to access, outreach and inclusivity, student empowerment, and the collective diversity in expertise, settings, and perspectives.

A new professional society called the Global Academic Maker Society is being created by HEMI to foster the use of higher academic makerspaces within higher education [12]. Membership in this society will promote best practices, the formulation of collaborations, and the distribution of knowledge to enable safe and effective makerspaces that maximize their impact on the student educational experience. Details on this new society are still being developed, including the membership fee structure and sponsorship opportunities.

These initiatives present a few opportunities for members of the international engineering education community to interact and learn from each other. It is expected that the trend to develop academic makerspaces will continue, with the work from these initiatives making those developments easier to implement. The increased collaboration among academic makerspace advocates shows great promise as a means to identify and share best practices, thereby enabling existing programs to improve operations and programming.

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