2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
ASEE
Paper ID #38881

Making Spaces to Supporting Formal, Informal, and Nonformal Learning Spanning a University's Design and Makerspace Learning Ecology

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Making Spaces to Supporting Formal, Informal, and Nonformal Learning Spanning a University's Makerspace Learning Ecology

Introduction

This cross-case case study [1] project aims to ascribe characteristics of differently oriented makerspaces across the learning ecology [2] at a singular institution. By cross-examining three specific spaces inside a singular institution that emphasize a range of formal, informal, and nonformal learning contexts, we highlight considerations for physical, social, and cultural contexts, as well as founding design principles, metrics for success, and scalability and sustainability of each space and the associated culture. Furthermore, by using an otherwise homogeneous corpus, this work can highlight the similarities and differences between makerspaces in educational settings and how those characteristics contribute to the development of individuals within the space. With the introduction and ongoing incorporation of principles from the Making Community into the curriculum, engineering colleges have begun modifying existing project spaces and creating new makerspaces to reflect the developing pushes in education [3,4]. However, the ongoing initiatives to reflect the more creative and less rigidly designed nature of making can be challenging to implement since many ideas are, or seem to be, counterintuitive to existing organizational structures within traditional academia. This difficulty is especially true in engineering-focused entities where the parties that have historically managed existing workspaces and their resources may not be as familiar with the pedological approaches and philosophies behind these areas. In addition, by the very nature of making, many common trends in makerspaces present unique challenges for the management; often, they require a very abstract look at the purposes and function in the settings they will operate inside.

Context and Goals

Within a STEM-focused undergraduate school, we have identified multiple workspaces available to students that provide aspects of makerspaces. The school primarily focuses on applying STEM learning through hands-on learning, design and project-based learning. This mentality around practical engineering and learning is derived from the school's history, where there are common trends within the student body due to the traditional demographics, geopolitical factors, and a long history of team-based learning and industry focused education. As a result, the school's unique culture allows a more direct comparison between spaces and elements within the learning environment -ecology- that the students and faculty operate within. The smaller nature of the school means that broad cultural values can be applied more readily to the larger student body, with common goals and mentalities allowing a broad generalization of the student body as somewhat homogenous, which is assumed to minimize outside factors to the analysis of how the organizational structures effect learning between spaces.

Library Makerspace as a Starting Place for All

A newly developed Library Makerspace (see Figure 1 below) was installed in the academic year of 2022-2023 as part of a series of initiatives in the newly renovated library space to further promote student engagement and learning. This space is notably special in that it lacks a disciplinary basis – that is to say it isn't managed by any academic disciplinary department – but is managed and run by student life and engagement, primarily as an additional space that can provide personal and professional development for students in their academic endeavors. Students are encouraged to engage with the space in a very free-form way, where tools and equipment are available for use and staff are there to ensure the equipment is run safely, but not explicitly to coach. Learning in space is entirely self-driven, with structures inside the space being largely for the purposes of encouraging safety and collaboration, rather than explicit learning and engagement. This space represents a new, intentionally built makerspace that has not yet developed a community of practice surrounding it and is presented as a space for all students to use, both for academic endeavors and also for fun, personal projects. Within the broader context of the campus, the Library Makerspace is largely planned to be a launch pad for the broader campus, where students can begin engaging with project at a low to non-existent barrier to entry for projects, to spark an interest in extracurricular learning. As the student's interest in projects grows, and they begin to explore higher complexity concepts, they should outgrow the Makerspace and move to other build spaces on campus that offer more specialized techniques and higher skill ceilings, like that of the Foundry for metalworking or the Mechanical Engineering laboratories for manufacturing and design. The informal nature of the space is to facilitate a low barrier to entry for students, so that a larger quantity can begin developing skills before outgrowing it and moving on to more appropriate labs and projects in other areas of the campus.

Figure 1: Library Makerspace

Figure 2: ME Manufacturing and Design Lab

Mechanical Engineering Manufacturing and Design Labs

The Mechanical Engineering department serves as the most striking contrast to the Library Makerspace, nearly to being the complete opposite in regard to management and history. Within the context of the school, the mechanical engineering department has consistently been the largest and one of the oldest departments for the school. As a result, the learning visions and priorities have shifted through the years, resulting in the modern-day design philosophy and learning structure the ME department uses. Within this paper, the usage of the term "Manufacturing and Design Labs" (see Figure 2 above) refers to four labs that would be the most familiar for students. First is the Metalworking lab, which refers to the full metalworking space involving CNC machines, metal lathes, and a variety of other higher skill manufacturing equipment. Second is the complimentary Wood Lab, which while smaller serves the majority of needs of students for building using wooden materials. Third is the "Aquarium" which is the 3D printing lab space available to campus. Lastly is the most recent addition "The Reef" which serves as a low fidelity mechatronics lab where students can work with low voltage electronics and mechatronics principles and components.

These spaces represent the most classical approach to operating build-spaces on the campus, with an abundance of resources available to the students. With industry partners, students can access a variety of materials free of charge aside from tuition, with options for financing individual projects and materials available on a case-by-case basis. While these labs are available for usage to the entire student body, they are often dominated by ME students or interdisciplinary clubs since the spaces are largely designed with the intention of supporting design courses within the ME curriculum. Specifically, the design pathway includes a first-year design course that serves as a formal introduction to space [5,6], with CAD and a team-based fabrication design project serving as its foundation [7]. Then a second-year course for introducing students to design thinking and designing for manufacturing and getting students comfortable with manufacturing individually [8], a third-year course for incorporating electronics and mechatronics [9], and lastly the senior design capstone courses. Notably within these spaces is a focus on safety and professional practice as a point of explicit learning goals.

Lab Space to Support Low and High-Fidelity Prototyping

The third space examined at this time can be described as a combination of the previous two spaces, referred to as the Product Design and Development Lab. This space is funded by the Mechanical Engineering department but is run by staff involved in the Maker Community and familiar with its concepts and approaches, which allows to serve as a bridge between the Library Makerspace and the Mechanical Engineering Department Manufacturing Labs. Put into place several years ago, this space demonstrates the most classic idea of a makerspace outside of higher education and is thus much more suitable for reference when comparing against preconceived ideas and understandings. While having higher technical availability than the Library Makerspace, students are encouraged to use the space as a work area for any skill level of project, with outsourcing happening in the case of specialized processes. Tools like a laser cutter, 3D printers, as well as low-fidelity prototyping materials are made available to students to support their course projects as well as student engineering competition teams. In practicality, this space is used by older students familiar with the Making movement, who often have need of the higher technical resources of the ME Manufacturing Labs but aren’t explicitly tied to the organizational structure of those spaces. This encourages students from a wider variety of disciplines to work in the space and facilitates a more communal atmosphere within it. Often people are introduced through personal connections, and often the space is used for working on formal project with a less rigid process than what is used in other ME build spaces, leading to the adoption of the term “nonformal.”

Literature Review

Examination of Maker Values in the Designated Spaces

In these three spaces, there are many comparisons to be drawn between them, but most notably can act as microcosms of different approaches taken inside of higher education regarding the implementation of Making principles into workspaces and their learning experiences for students. Using the principles developed previously by [10] a broad view analysis can be performed of each space. For the purposes of analysis, let us revisit and define the six values from the previous work.

First, sharing inside of Making comes from the practice of sharing information, ideas, results, and any number of elements from projects taken on by members of the community. As compared to traditional academia and industry, the Making community freely promotes a flow of information between members to encourage new ideas and further innovation. Second, is the value of Practical Ingenuity, where work is done extremely counterintuitively to the traditional engineering design spines. Makers are characterized by a very agile approach, with iterative building and prototyping often coming before any analysis or usage of advanced manufacturing tools, often focusing more on "Proof of Concepts." This in turn leads to extremely out of the box solutions, and optimal results that produce creative and unique results that couldn't be produced with traditional approaches. The third value discussed is Personal Investment, where Makers take a form of ownership from purely intrinsic motivations, rather than extrinsic factors such as grades, experience, or professional reputation. Especially at the school examined, there is an extreme focus on how education and its effects later on life, which is a major motivation for students. Makers in contrast often are experimenting completely without immediate rewards, like the banker who thinks that making a metal sculpture is fun, and is more comparable the enthusiasts and artistic expression. Fourth is the idea of Playful Invention, which is often can be seen as one of the most lacking aspects in certain engineering aspects. Like Personal Investment, this can be seen as an aspect of underlying motivations and creativity within the students and Makers themselves. Inventions from the Maker community often are extremely creative, fantastically flippant, and have aspects of fun and joy within them. From aesthetic touches to unnecessary additions, there is a very real "It was just interesting" elements to production. The fifth value exists within "Risk Taking" where Makers are incentived to fail early and fail often, within their explorations and projects. Experience is gained from the iterations, the failed projects, the ideas that never started. Rather than arriving at the correct solution the first time every time as is heavily encouraged in traditional learning, failure is a badge of honor. It shows that the members tried and failed, but still kept going, eventually leading to success with far more personal experience. The sixth value examined is the idea of Community Building, which was mentioned when exploring Sharing. A critical aspect of the Making Movement, and arguably one of the largest reasons for its success, is the community surrounding it. Forums, fairs, and books are available for free, or at least very little charge, and the barrier to entry is almost non-existent. Often, there is a draw into it, and mentorship and comradery allow an emotional stake for anyone joining the movement. Lastly is the value of Self-Directed Learning, which seems to have elements of each value within it. Each Maker is encouraged by their community to explore concepts take risks, explore ideas with ingenuity, take a playful approach to their personal ideas, and share lessons learned and what came out of their projects. The entire idea being that Making is simultaneously so personally motivated by unadulterated curiosity, but also by a community to support the exploration of ideas.

The machine shop and 3D Print Labs possess attributes of Practical Ingenuity, Personal Invention, and Community Building through a peer mentorship support system. Students are encouraged to bring in their own projects, which are inspected by certain management personnel before being approved. Students then work with a mentor to produce their projects and have the opportunity eventually to work in the spaces given enough time and experience in the labs. The library, on the other hand, presents as a new, relatively undeveloped area. While the previously discussed labs have a strict hierarchy and approach to be followed, the library makerspace is a newly developed area that doesn't have a pre-existing organizational structure. In the current development life of the area, it is supposed to encourage values of Practical Ingenuity, Personal Investment, Playful Invention, Community Building, and Self- Directed Learning as a Makerspace within higher education. However, the interesting aspect of the space is that these values haven’t been completely solidified within the culture and space itself, since it is still under development. While there exists a loose goal that is becoming better defined, the how to achieve it still exists within the nebulous future, and the participation of students. Lastly, the existing Product Development Lab recently was upgraded to better support a growing vision and its makerspace roots. While designed as a Makerspace, limits within the previous years and the recent upgrades have allowed a re-evaluation of how work is approached and ran, along with its function as it can support larger projects. It is run by individuals who have been extensively educated on maker pedological approaches and represents the seven ideal values of a maker-based learning experience. However, the support is much more limited than that of the library due to a specific focus on supporting specific classes.

Figure 1 Summary of Shared Values

Value	***Definition***
Sharing Inside of Making	Promoting the flow of information, observation, and knowledge between individuals and groups
Practical Ingenuity	The idea of developing functional prototypes and having a very agile approach to development, characterized by “Fail Early, Fail Often”
Personal Investment	A form of ownership from purely intrinsic motivations, rather than extrinsic factors.
Playful Invention	The idea of Making not as a functionalistic process, but a form of creative expression bordering or coexisting as art.
Risk Taking	An idea of fearless innovation with failure and risk serving to develop project and individuals
Community Building	Mentorship and comradery allow an emotional stake for anyone joining in Making.
Self- Directed Learning	Participants are encouraged to personally develop and chase personal interests and goals.

Research Methods

To discuss each space in more detail and perform a qualitive analysis into how the motivations and constraints of each space effects its ability to encourage Maker-Based Learning [10], a systematic approach will be taken to examining each space. Each space will be researched and examined in 4 ways, to allow more direct comparisons to be drawn, and more detailed information to be available. First,

The research methods to be used involve a systematic and comprehensive approach to examining each of the three designated makerspaces and performing a qualitative analysis into how the motivations and constraints of each space affect its ability to encourage maker-based learning [10]. The researchers aim to gain a deeper understanding of the following elements of each space:

- The underlying organization structures of each space
- The context each space operates from and has developed from,
- Operational limitations, perceived vision of each space by different levels of management.

To achieve this goal, a three-step process has been developed to provide a broad analysis into these elements of the spaces. Each step is designed to address a specific facet of the objectives listed above, with the first being a series of interviews performed with different levels of management and administration. A look into the organization(s) running the space will be done through qualitative, semi-structured interviews with important individuals within the management or simply experienced with the running of said spaces with management and administration with critical incident interviews [11]. Informally, 14 students have been approached to verify information, although the informal nature of discussions is more appropriate for the second step of methodology.

The interview protocol is a semi-formal, meaning that conversations were largely allowed to be organic, to explore facets of each space that may not be initially understood, or that the interviewee thought important for understanding the success. The protocol is broken into two sections but largely can be simplified as Contextual Questions, which discuss the perceived purposes of the organization and the space. Notably what the ideal goals would be met, and what are the limitations faced through educational, safety, and institutional requirements. This allows a better understanding of the context the space operates in, which can be used when separating factors that influence students' learning and the outcomes of these spaces from the factors that come from the management of the space, and identifying reasoning behind choices in the organizational structures. The other questions are Operational Questions, which detail the management structure explicitly, how leadership works within the space, and how the visions and goals are implemented.

The second step involves examining each space through observation and direct participation. By doing so, the researchers aim to provide a more practical understanding of how the makerspaces are truly run and to acknowledge incongruities between what was discussed in the interviews and the actual daily operations of each space. This approach will provide a contrast between theoretical and applied support of these makerspaces, to see how the goals and vision of each space are show up, and better evaluate the spaces. This observation methodology will be conducted whenever possible over the course of the research. Do the breadth of what could be observed, there isn't an established protocol for observation, so as to avoid limiting focus and creating unintentional "blind-spots" when interacting with the spaces. However, special instruction to focus on the normal operation is provided, specifically the typically activities of students, the workflow of individuals in the space, the attitude and culture developing, and the nature of projects and interactions within the space.

The third approach involves critically dissecting and mapping the observations, interactions, and experiences of the researchers during the long term second step to the points brought up during interviews within step one of this research project. This cross-examination between the spaces will then be mapped to the Makerspace Virtues discussed in the literature analysis, and provide critical information for the effectiveness of each space, including the strengths and weaknesses of different approaches. By having explicit understanding of the operation of the spaces by way of interviewing management and critical people, and the observed understanding of the practical operation of the spaces, it should allow insightful cross-examination of how management and culture effect the learning of participants within these spaces. Overall, the research methods are designed to provide a comprehensive and detailed analysis of each makerspace. We hope to gain a deeper understanding of the unique challenges and opportunities that each space presents, and how each space can be optimized to encourage maker-based learning. The research methods discussed will provide a valuable framework for future research into makerspaces and their impact on the learning experiences of students. Overall, the research methods are designed to facilitate a broad understanding of each space for future work to be built on, and a glimpse into the current operation of each space. We hope that by gaining a deeper understanding of the unique challenges and opportunities that each space presents, they can optimize each space to encourage maker-based learning.

Results and Analysis

Library Makerspace – A Nebulous Start

When observing the library and interviewing two members within the organizational structure, the experimental nature of the space becomes very apparent from the breadth of personal projects and just how the space begins being utilized. When entering the space at almost any given time, there is three to five groups of students in different areas all working on different things. Some are working on personal projects, such as sewing or one-off designs for problems they are designing solutions for, while other students are working on homework, and some are using it as a social space. From the administrative standpoint, the space is supposed to serve as a community hub and as a launching point for students to begin personal and professional growth with non-traditional extracurricular activities. Specifically, it is targeted towards students that have some sort of barrier to entrée, such of social norms, risk of failure, or inexperience. To this end, the space is supposed to be the first place where students can begin their experimentation and start their own self learning within the school. Inside the Library, mistakes are minimized by the low technical entry, practices incorporated by the space manager, and most importantly by an accepting culture. A failure is much more likely to be met with questions about what happened, laughs, or light concern than any real repercussions. However, the developing nature of space leads to a surprisingly low number of personal projects. Often the space is more a thinktank where ideas can be shared, and community develops, rather than a space where projects are worked on outside of conceptual development.

In regard to the vision and the context of the space, the Library is a very open area that has many elements that are yet to be completely solidified and investigated, which makes it extremely important to understand it's roots. Started by an increasing movement in the school to try and engage students in personal projects early and facilitate personal investment into learning, it has undergone numerous iterations in its purpose. Originally bookmarked when the library itself was being developed, the Makerspace was much more of experiment than any other space. When interviewing an employee, they specifically stated the following for the intended purpose. "(It's) just student exposure. Just student exposure. Because we get students that come in here, they think they want to do engineering, they think they want to do a design, and they're not exactly a hundred percent sure what goes into that or what they can do with that…But I think exposing them to, "Hey, here's some tools you can use. Here's some design work you can do. If you need anything cooler or more specialized, here's the places you need to go." Yeah. Just student exposure, student outreach, just connecting resources as a central hub." This is further supported when discussing with administration what they were discussing their experiences and goals with the space. Specifically, they were using the library makerspace as an area where they could hook in unrepresented groups, and students who don't "see themselves" in the industry focused project the school is famous for. Rather, the makerspace is a place where any student can wander in and begin seeing themselves in making, and start making the first early mistakes where they can learn about how to engage and how to begin thinking critically. Contextually, this is very much in line with the support from the larger department of "Student Success" which specifically is focused on student engagement outside of their academic pathways. The library operates within a school of very dedicated industry focused projects and the corresponding culture, and seeks to address the limitations, notably the daunting process of beginning. It was noted that many students who don't come from a technical background are often lost during their time, failing to find a personal way of getting into engineering. While they may be able to perform academically, they often feel as though they are unable to grow outside of the classroom from not having an approach or pathway that they can take, and the Library Makerspace largely positions itself to address this disparity by its informal casual nature, which they want to hook in students as the launchpad.

In terms of organizational structure, the library primarily functions with four levels of interactivity. Students, Student Employees, Space Manager, and Administrative Personal. When observing the space, the students largely seem to use it for two purposes, a communal connection point to discuss hobbies and projects, and for specific tasks and the tools within the space. The students who use it for a communal connection point primarily benefit from having likeminded peers, however, notably do not regularly engage with personal projects, instead using it as a study space where they can be louder and have off topic conversations. The largest benefits to this group derive not necessarily from practicing hard skills, but being surrounded by like-minded peers who support their classwork and share similar interests. The second group of students who use the space for specific tasks make up the majority of the engineering and personal projects that move through the space, and are notably less communicative than the social students. Aside from specific personal connections like partners or friends helping on the project, these students primarily spend far less time in the space, instead opting to use available resources and then leave without excessive interactions. The student employees are notably split similarly to the non-employed students among similar differences. The student employees who are friends with the community groupings often are more socially connected, and produce less projects and personal work, but instead are more involved with maintenance and management of the space. The employees who engage less socially but are more focused on their work often are using the employment to leverage the resources for personal projects, and there has already started a trend where they will move on to employment in more advanced areas of campus after a brief employment at the space. The student manager is interesting, in the fact that they largely set the tone of the space and how lower levels interact with it. Being a student themselves, they often are in the space studying and involved with the more social individuals themselves, but will often break away to help with the project-oriented individuals. They often are the inspiration for projects produced by the social students , often serving as a mentorlike figure to younger ones, or an encouraging peer to my socially equitable ones. The administrative personal rarely directly interact with the space, instead directing through the manager figure.

With this organizational structure, there is notable constraints and weaknesses that occur within the space. As a brand-new space on campus, the area has a number of logistical issues stemming from undeveloped and tried backend support. While there is billing processes in place and it has copied from other departments, the Makerspace routinely runs into issues with supplies and funding, and frequently has logistical issues that hamper infrequently used resources. The culture itself is also dramatically changing, and can't be appropriately summarized within this paper. During time of observation, the space went from being largely unused aside from a consistent group of social students and largely dominated by project-oriented students to being much busier and largely occupied by social student, with project-oriented students rotating through consistently before moving to other areas of the school. The most notable results of observation is the difference between administrative personal's visions and the actual operation of the space. While the vision of the admin seems to most closely align with project-oriented students, the lack of direct management, and the usage of a student operating the space significantly alters how the space operates. Rather than being a lab, or a dedicated space, the informal nature means students tend to reenforce social connections and values instead of the more professional education focus that the vision of admin is centered around. In regard to Maker Values, the space primarily promotes Sharing, Playful Invention, Community Building, but notably undercuts project focused Development, including Self-Directed learning, Risk Taking, and Practical Ingenuity. By promoting an informal atmosphere and completely self-directed learning, students are much more inclined to lessen learning and promote social and soft skills.

Product Development Lab

The Product Development Lab is a chaotic space where random elements of creativity are seen in nearly every aspect of it. Old projects are kept around, often being disassembled and used in other projects. If something looks interesting or has creative elements, it is saved and preserved to spark the next idea. At any given time, there are three or four projects in various stages of completion being worked on, with participants often bouncing ideas off each other while curiously eyeballing and planning the next step of their project. The informal nature of the space leads to more of a relaxed policy where participants can suggest any number of projects and immediately have a surplus of random materials available. It is a very casual atmosphere, where formality seems to fade away, leaving just a simple approach that characterizes much of the Maker Community. Often the design process appears to follow the order of someone being curious or having a project they want to approach, bouncing ideas off several people, and then going at it using whatever tools they have available or whoever is willing to help. This chaotic nature seems to be the appeal, where higher technical skills can be used without the restrictions that exist or are perceived to exist within the manufacturing labs. However, the proximity of the two spaces leads to an exchange of ideas and some mingling, with individuals often wandering between areas to complete different aspects of projects.

The Product Development Lab can be viewed largely as the traditional makerspace analogy for the research, given that at all levels the space is designed with classic Makerspace values and philosophy. Started by a professor with a passion and extensive background in the Maker Community, the lab started off as a corner of another lab before being recently upgraded to its own full build space. The vision itself is often described as "A place where students can come in, mess around, and just do interesting things" by the professor, it was built from the ground up to facilitate two visions. First, the support of early prototyping classes taught within the ME department, which are intended to introduce students to design thinking. Second, the support of any student interested in their own project and exploration. The student researchers and upperclassmen who get involved often come from two avenues, either having been invited by an existing participant or being posed some variation of "Isn't it interesting how?" by the student-researchers and the professor who work within the build space. Notably though, there is almost no incentive to be in the space, with students being offered the space to work in but not expected to, and the personally invested students being there through their own curiosity of having become involved through some other means. The space is just a resource to use, and often is in varying states of chaos, but nearly always has project that are being worked on, leaning more towards esoteric and artful expression.

Organizationally speaking, the space largely has three levels of interaction inside of it. The first is that of traditional students, who often come to the space looking to work on projects. They often have a goal in mind, but want to work on it in a nonformalized way and just following nonlinear learning that is promoted by the administrative personnel. They come in as groups or with one of the upperclassmen or the managing professor, and often will end up spending several hours just experimenting and messing around with projects, with the time decreasing as they get more experienced. The second level of interaction is the undergraduate researchers, which serve as the consistent participants in the space. Often having been students as previously described, normally they are individuals who appreciated the values and philosophy that suffuses the build space, and want to stay within it while pursuing personal interests. Often they are prompted for their work by considering personal frustrations, passions, and other activities and take outside motivation and approach it in a mentality of a Maker, rather than an engineer. Consequentially, there is often an overlap between these upperclassmen researchers and a higher skill base, as they often are intrinsically motivated and use the space not just for research, but many of their other projects. Lastly is the management individuals in the space, notably the professor.

Unsurprisingly, the space is largely limited more by the creativity of the students and school protocols than anything else. If a student wishes to pursue any topic, the space is free to be used unless there is resources not available to it, in which case the proximity to higher technology labs allows students to move between spaces as needed. In regard to Maker values, the space is the best representative of the seven values. Sharing is promoted by the team based and communal approach of the mentorship and comradery between student, also associated with Community Building. The space specifically has an abundance of low-cost materials and resources, with low fidelity prototypes being very encouraged, promoting Practical Ingenuity and Playful Invention. The culture itself promoted Risk Taking, Self-Directed Learning, and Personal Investment through the support of upperclassmen, the project-oriented work, and moderation by the management.

M.E. Manufacturing Labs

The M.E. manufacturing labs serve as the most complex, but traditional structure regarding the idea of academic build space, and is deserving of a paper to themselves. The complexity of the context and history surrounding this space become extremely clear when interviewing about the space and determining the volution within. The interesting aspect of the space is how it originally started as a teacher-led supplement to courses to teach manufacturing, however, grew to a peer-to-peer learning environment. However, there are key points that can be derived and are critical to the culture and organization of the space that can be interpreted. The department itself has three critical elements that must be considered when evaluating. The first is its project-based learning philosophy, which stems from it background with students that prefer hands on learning, and used the school as an academic focused trade-school to learn engineering for industry, rather than focusing on it as an educational facility. This is important, since that focus on applied education manifests in nearly every aspect of the M.E. departments decisions, and is especially important in its build spaces. The second, which stems from and compliments the project-based learning is the heavy emphasis on industry partners and learning for industry. The students and the department both have a tremendous focus on learning skills to impress partners, and the partners heavily encourage and reward the focus on this style of learning.

"I think that … the [university] has historically had a certain type of student. When I was here, when I was a student in the '80s, I would say we were 50% farm and ranch. Everybody knew how to build. Everybody had hands-on learning. I was urban. I had my set of skills. There was an element of training, but it was just common knowledge. I mean, there wasn't a lot of training here. But I think already then we had set ourselves apart. I mean, not think. I know the [university] had already set itself apart because of our geographic location and the types of students we were producing. We developed a certain type of customer on the other end for our industrial partners that expected that out of us."

Third is a focus on safety within the spaces, which is the absolute focus of the current administration. No tool is run unless someone qualified is aware as supervising, students are held to tremendously high standards for conduct, and everything is meticulously planned out.
This becomes tremendously relevant when discussing the organizational structure within the build spaces. There is two components to discuss, which is carried across each space regardless of the project or student, since the M.E. department largely is concerned with serving the school, and has designed its build spaces to be flexible and adjust to any needs. The first consideration is the process for which projects are approved and worked on. Conceptual work is often done

separately from manufacturing, in classes, clubs, or personal time. Once a product is conceptually built, typically being a near final solution or a critical step during development, a formal document is brought to the labs where the individual will discuss their idea with an experienced mentor. From here, pending approval, the student is guided by the mentor and coached on how to improve the product, repeating until the project is ready for production. Then, the student is coached on whatever processes they need to complete their project, and worked with until final assembly or the equivalent. The notable elements of the process is that it is a very formal process, and the mentorship figure. The process is exactly that, a process that must be followed. Attempting to bypass it, or take shortcuts often results in repercussions, and is enforced by every level of interaction. There is very little casual prototyping, and the process is instilled in every student involved with the spaces. The other notable element is the mentor figure, which is used as safeguard and resource for the students. This is explicitly one of the strengths of the system, since the peer mentors are often upperclassmen who have worked in the build spaces extensively and have received extensive training on operating the machines. The usage of students in this role takes away from the daunting formality, and is direct result of trying to engage student further and incentivize long-term learning. The usage of formal student mentors means that individuals often get far more personal experience and time about the technical end of development, and fosters an attitude where if a product is designed, a way to make it will be developed. The can-do attitude and the formal learning seems to encourage students and provide structure to learning.

"I think there's a level of comfort that comes with the students learning from our mentors that we don't get as a professor, particularly with what we're teaching, because I'll just say there's some of the stuff early on that some of the students we were teaching early on, and we've really gotten away from this, where they were so intimidated by what they were doing that they weren't learning anything. Honestly, you take somebody who doesn't know how to run a screwdriver, and then you put them on a lathe, and just the level of discomfort that they have causes them to be… You're just not getting anything out of it…. I can say the mentor team we have right now, but the mentor team is self-building. The mentors pick the mentors, so we've got a mentor culture that has become very comfortable for the students to approach, and not only for the students to approach, but also very comforting for the mentors to onboard themselves. Not everybody can be a mentor. It's really about leadership and drive and interest. But the ones that have that, I think we have a program where it's so comfortable for them. If they have the right attributes that are identified by the other mentors, it's a comfortable onboarding process. Then we make the students comfortable. By being comfortable and having standards and practices, we also keep it safe."

Findings and Discussion

This leads to the discussion of results, where the individual spaces can be used to model larger contexts and situations that makerspaces in higher education may face. The results themselves are incredibly interesting when compared with the ideas and logic that were expected when initially approaching the research. Originally, the Library Makerspace was anticipated to have a very high number of projects, while having relatively low technical entrée and project natures. It was anticipated to have low fidelity, but mass quantity and students to often start here before transitioning to other spaces. Aside from the small one-off prints and individual projects that

people are using the tools for, the only aspect of large-scale projects often reflected is conceptual development, with the majority of prototyping happening in other areas of campus.
The Library Makerspace realistically serves as a community center and initial concept development hub for students, but only produces lower complexity projects, with continual learning being continued in other more suitable spaces, fulfilling its purpose as a launchpad for students. The space primarily functions as a communal connection point and for specific tasks and the tools within the space. The library makerspace primarily promotes social values but notably undercuts motivation and continual learning.

The Manufacturing labs in contrast to the library promote very little conceptual design, by serving as the remainder of development. While the concept is done almost entirely outside these spaces, tremendous creativity seems to be inspired by the ideas of how to manufacture parts, testing, and the mentorship by peers. It sees a far larger volume of projects from class a personal interest than the library does, and seems to have the ability to foster far more curiosity and depth of understanding than either of the other Makerspaces do. The mentorship figure is explicitly one of the strengths of the system, and minimizes the downsides of the formality of project approval. While it may be the most complex and traditional of the three makerspaces, serving as a project-based learning environment for students that prefer hands-on learning, it strongly encourages long term learning and higher complexity projects for students who learn to work within it. The organizational structures of the three makerspaces are unique and reflect the institution's focus on student engagement and industry partnerships in different ways.

Results from the study reveal that the three makerspaces in this educational institution are distinct in their organizational structure, student attitudes, and project types. The Product Design Lab seems to serve as a functional middle ground for the two spaces, with nearly every aspect of development taking place. Aside from specific processes, the entire life cycle of a product seems to exist within this space. From the initial conceptualization of the problem and solution to initial testing, all the way until the majority of prototyping, the only work that seems to leave the space is high fidelity production, which it simply isn't equipped for. In short it is the best served for encouraging Maker Values and creative prototyping, but is limited heavily by its technology, relying on other labs to outsource higher complexity work to, while preserving its unique design philosophy. Through the support of upperclassmen, project-oriented work, and moderation by the management students are encouraged to pursue their own interests and explore, without the daunting limits of formal procedure.

Important findings from the study reveal that the three makerspaces reflect different aspects of success, with each space serving a unique role in the development of student projects and their learning. The Library Makerspace serves as a community center and initial concept development hub for students, but lacks the ability to produce high complexity projects, and consistently motivate projects and learning outside of student driven interest. The Product Development Lab is best for students when they adopt the philosophy, which is easy, but can't support high complexity projects and relies on the M.E. department to support hard skill learning. The M.E. Manufacturing Labs serves as a project-based learning environment for students that prefer hands-on learning, and a peer-to-peer learning environment, but is tremendously daunting because of its rigorous and formal process for project approval.

Implications and Future Work

Future research will explore more formally each makerspace, developing methods to get quantitative data, as well as the history of each space and better information about the projects in each space, students' successes, and how they are used. The study raises generative questions about how agency and ownership affect the community and space and how the management style encourages or discourages personal investment in Making.

In the future this line of research will grow to explore more spaces such as the foundry and the engineering competition extracurricular program. Further work will be put into better explaining areas and management structures. Lastly, after qualitative research is completed, there is plans to move forward exploring the history of each space, along with gathering quantitative data about the projects in each space, students' perceptions, and how they are used.

Generative questions have come up about how does agency and ownership effect the community and space? How might the management style encourage or discourage personal investment in Making? There are many factors beyond just the tools and fabrication processes available is a space. Future exploration of multiple spaces at a singular location may make it possible to understand the phenomenon of designing in an array of Makerspaces quite possible.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant number #2010696. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The authors gratefully acknowledge the participants in this study and the contributions of our research team.

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