Walking the Walk:
Iterative Design in Student Staff Service Learning Projects

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INTRODUCTION

"Iterative design" is a buzzword bandied about more liberally than its principles are employed; what happens when we embrace intelligent risk-taking and empower students with legitimate agency to solve the myriad struggles of building a makerspace, running the space efficiently, creating marketing materials, and utilizing the tools within to make the world a better place? At the University of Texas at Arlington FabLab, we genuinely attempt to apply the ethos of iterative design in all our endeavors, though this has been most overt in the special projects accomplished with our student employees; we hired smart students from a variety of majors, trained them to operate digital fabrication equipment, and then assigned them to apply themselves to specific problems individually suited to push their boundaries of what they had learned through coursework by "plac[ing] curricular concepts in the context of real-life situations,"[1] creating earnestly impactful learning experiences.

Operating an 8,000 square foot facility 7 days a week with only 3 full-time staff is neigh impossible, so our strategy has depended entirely on building our student staff's machine competencies and leadership skills. We range from 25-45 student employees depending on the semester, and have made an intentional choice to hire from a broad cross-section of the campus community, from incoming freshman art majors to PhD candidates in Transatlantic History, students who have never left Texas to international students living thousands of miles from their parents. Engaging a diverse peer-leadership model not only allows the FabLab to connect more broadly to our campus's equally diverse student population, but also provides us with a platform to create the interdisciplinary, inquiry-based ecosystem we wish to cultivate in this makerspace. As an R1 institution[2] focused on experiential learning as part of our Quality Enhancement Plan[3], we strive to imbue our student employment opportunities with the same standards for leadership, creativity and initiative as our full time positions. To that end, FabLab full-time staff and student employees work together to identify problems and needs within the space and work under the mentorship of the lab technicians to ideate, prototype, and create solutions. The student staff carry out the specifics of the design and prototyping work, with progress critiques, additional brainstorming sessions, and mentoring by lab technicians as needed until a working product is realized; the intent of this experiential learning initiative is "to equally benefit the [student employee] and the … [FabLab, with] equal focus on both the service being provided and the learning that is occurring."[4] Based on the relative skills and enthusiasm of the individual student(s) involved on a given project, these interactions have ranged in nature from normative supervisor/employee to something resembling a teacher/student relationship, with many taking on the feel of collaborative efforts and, in the best case scenarios, "beyond complementarity, where both mentor and protégé contribute to and benefit from their relationship, to mutuality."[5] As the needs of our expanding lab grew, our most promising students' aptitudes blossomed through ambitious directed projects.

METHODS

This paper will focus on five case studies of our most aspiring endeavors to date involving student staff service learning. Project scopes include: modifications to an open-source network solution for remote command of multiple 3D printers; a web-based system to track machine use, streamline 3D print retrieval, and gather de-identified user demographic statistics; a series of graphic art posters for each of our major pieces of equipment; building a four-color silkscreen press based on extensively modified open-source plans; and two separate prosthetics projects – one for a French Mastiff, one for an eight year old human. Students learned to make project/budget proposals; the Libraries funded the purchase of requisite supplies, freeing gifted students to invest themselves in project success.

By the time students reach a four-year university, they are well accustomed to the cyclical predictability of assignments, term papers, and final exams. High-performing students are often jaded with undergraduate course materials, either because they are introduced to so many concepts that they simply don't have the time to study the fascinating aspects in any great depth[6] or as a result of the banality of the testing cycle where good grades are often achieved by "looking for the facts they think they will be tested on, not for the meaning of the material"[7]; a surface-level echo of the way sitcoms address a serious concern with trivial simplicity in order to fit the content into the packaged time slot[8]. This frustration exists amongst students and professors alike, though it appears to be a rather inherent aspect of the modern university experience[9], with opportunities such as internships and undergraduate research initiatives intended to provide a stimulus towards increased complexity of thought[10] for those with spare time[11] and perhaps some surplus intellectual curiosity. Eye-opening and momentous as these out-of-classroom, "real-world" opportunities may be for students[12], they most often remain tied to the cyclical structure of contemporary academic life[13]. The most radical aspect of our pedagogy presented in this paper has been the transcendence of the semester; the open-endedness of the problems we challenge our student employees with demands

sustained attention to multidimensional learning in a way that categorically cannot be encapsulated in a system dependent on the assessable finality of assignments on a pre-determined schedule.

RESULTS

OctoPuppet

We have been remarkably fortunate in several regards, not least of which that we have a large space full of equipment. One of the most consistent problems of rolling out new equipment for learner use is figuring out how to rearrange a finite amount of space to accommodate additional machines and workspaces, a problem we were dealing with on a daily basis in our small "beta-space" we occupied from October 2014 to December 2015. Foreseeing the continued relevance of this issue even as we stood on the precipice of an order-of-magnitude expansion in square footage, we set out to find a solution that would allow us to get away from dedicating a desktop computer for every 3D printer. We saw this as a way for us to engage in space planning for the future addition of more 3D printers, accounting mainly for the footprint of the machine itself, not the added square footage and cost of a companion computer for every machine. Perhaps equally importantly, moving the printer's G-code feed from a desktop computer to a networked Raspberry Pi would allow us to attempt longer print durations; we had been experiencing problems with large prints failing due to computer crashes when a learner attempted to slice a large file while the computer was also running the 3D printer, and as the "Deep Freeze" system mandatorily installed on every publically accessible computer automatically reboots each computer at a specified time every day, and would mercilessly kill ongoing print jobs without the option to delay the Freeze or resume after the reboot.

FabLab technicians Eric Olson and Morgan Chivers worked with lead student employee Tushar Saini, a Masters student in Mechanical Engineering, to establish the parameters of what we were looking to do and what would be possible with current equipment and in light of the institutional limitations, with Tushar handling the bulk of the research to find potential solutions. The existing commercial products accomplishing remote-command capabilities offered far more centralized control than we sought, required use of a proprietary server-based slicer, did not track individual user information, and the company was seeking monetary compensation well beyond what our budget could ever hope to support. Fortunately, Tushar had also looked into an open-source program, OctoPrint, "a snappy web-based 3D printer control interface"[14], which at the time was without a method of machine-usage statistics collection and did not support the ability to control who had access to the remote-command web page for our 3D printers. Tushar was passionate about finding a solution to this, learning new programming languages and bolstering his competencies with the languages he already had some experience using, working to understand the existing OctoPrint code thoroughly enough to make substantive functional changes. Other student employees with coding skills were assigned to work on the Octoprint-modding project, with Tushar leading that team under Eric's

mentorship. Cumulatively, this team brought varying levels of programming knowledge; Python, BootStrap, JavaScript, CSS, jQuery, and JSON were used to modify the OctoPrint code and create a customized end product.

This derivative system, named OctoPuppet for its ability to marionette between KISSlicer, our 3D printers, and the Raspberry Pis, certainly got more complex and took longer than any of us had initially expected. However, in addition to the ability to send G-code remotely to printers through Rasberry Pis, the creation of OctoPuppet has yielded: a successful method for restricting the IP address to FabLab specific computers; an authorization step which prevents learners from initiating or canceling a print without first swiping their student ID card and agreeing to the terms of service; a method of scraping KISSlicer G-code to garner machine usage statistics such as print times, length of filament used, etc.; a customized graphic interface; a streamlined method for updating the Pi's; and a precursor to our usage statistics collection system (to be discussed further in the next section). OctoPuppet is available openly on the UTA FabLab's GitHub for others to use or further adapt to their own needs[15].
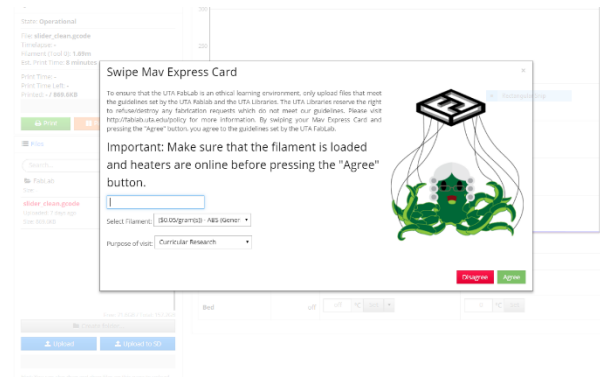
Figure 1: Pop-up within OctoPuppet, featuring Judgy. Students must agree to the Terms of Use and input usage data before printing will begin.

FabApp

As an entity born of a library devoted to strategic risk-taking and data-driven decision making, collecting usage information about the campus appetite for the FabLab has always been an integral part of our mission. For the first year and a half of our existence, this was accomplished by handwriting every user's name, ID number, major, graduate/undergraduate status, filename, date of interaction, start and end times, name of employee involved, and amount charged (if any) for every piece of equipment we owned, which at the time included 3D printers, a laser cutter, mini-mill, vinyl cutter, electronics station, and virtual reality station. At least, that was what was supposed to happen. Amidst the oft-intense energy of helping students start jobs, pick up completed prints, and troubleshoot machine issues, accurate paperwork was a common casualty of busy situations. To prove the popularity and utility of the FabLab to the campus community, we obviously couldn't afford to allow our peak usage times to remain anecdotal. We reiterated the importance of taking the time to fill out the paper tickets at staff meetings and held student leads accountable for ensuring all staff on shift were following protocol, and while

this greatly increased the percentage of lab activity captured as a trackable ticket, it also created a monster data-entry project every month that dominated an unsustainable amount of student labor hours. It seemed self-evident that transitioning to a digital input system would be a logical progression, though there were a variety of factors complicating a direct replacement of the paper tickets with a digital spreadsheet.

Inspired by this quandary, Business Information Systems major and Lead Student Jonathan T. Le designed a system through which the FabLab could simultaneously collect demographic and usage statistics while also transforming the FabLab's foundational workflow to allow for greater efficiency and increased user satisfaction. Jon pitched the concept of this middleware, dubbed FabApp, to the FabLab staff as a project that would satisfy the requirements for his senior internship course, but it quickly burgeoned into a multifaceted system that has proven absolutely central to the daily operations of the lab. Jon worked under the oversight of technician Eric as well as with the Libraries' Systems Librarian, Michael Doran, and our Director of Assessment, Heather Scalf, to construct the initial beta version of FabApp within the privacy and data storage parameters set by the University.

While the FabApp continues to grow and expand in its scope, at present, it is able to provide: publically viewable machine usage status in real time; storage location management of completed 3D prints; cost estimation for consumables before a job is started; cost calculation of completed jobs for our staff; integrated link to our institutional payment page; a waitlist system for popular equipment; consumable use statistics; and (with additional work by Tushar Saini) two-way communication with OctoPuppet to enable automated thermal ticket generation for all jobs. In the spring 2017 semester, we partnered with a Computer Science Engineering course to outsource further development of FabApp modules to undergraduate students developing their programming skills. This service learning project resulted in some usable code, and also introduced us to a new student who has since joined the FabLab team to continue assisting with this project.

The information collected by the FabApp has allowed us to make data-driven decisions about our hours of operation, quantify the increasing diversity of our equipment users over time, and streamline backend processes to improve customer service. Like OctoPuppet, the FabApp files are available open source on the FabLab's GitHub; aspects of the two systems are co-dependent upon each other.

Screeny McScreenPress

Jonathan T. Le, the same lead student who created the FabApp also brought a personal background of having run a small t-shirt printing business between high school and coming back to college. As the only two FabLab employees with serigraphy experience, Morgan and Jon discussed the FabLab's planned screen printing capabilities somewhat often. A sticking point we found ourselves continuously returning to was the administration's reluctance to invest financially in a 4-color press; we lamented that multiple color prints on fabric would be of limited accuracy, thus narrowing

Fig.2 Screeny McScreenPress, as built and as proposed

appeal to learners on campus. In our proposals recommending which technologies to invest in for the expanded lab, administration was initially not interested in a screen printing press due to the relatively high cost of a robust unit with accurate registration and the dominant footprint of such equipment; as a compromise, Jon and Morgan worked up a proposal to build a relatively simple, semi-disassemblable press ourselves based on an open-source set of plans[16].

Jon looked through the list of materials and found we could save some money by sourcing everything ourselves and buying online or from local hardware stores. We also identified a few design components that could easily be made far more robust for a little extra investment. Following in this vein of conversation, we thought of several other features that could potentially be built into the system given the fact that the FabLab has a ShopBot and the initial designer of the open-source press was working with non-CNC tools. With this recognition, Morgan and Katie asked Jon to create a proposal for what the financial and temporal implications would be if we built the open-source press as designed, if we made a few modifications to the open-source press plans and built that, or if we designed additional micro-registration features and made more significant modifications to the design rooted in the open-source plans. Jon's evident excitement about the potential improvements to the plans and the thoroughness of the presentation convinced us to opt for the more modified version; surprise-to-nobody-by-now, it took longer than anticipated. In addition to the normal meetings to go over designs and talk through problems before cutting, the physicality of this project brought another issue to the fore; Jon was exceptionally devoted to the project and would have been able to finish closer to the initially projected deadline were it not for the limited number of hours student employees are permitted to work each week. Abiding by this constraint necessitated that we reset expected checkpoint dates, and though this slowed the pace of progress, the process still resulted in a screen press, lovingly named Screeny McScreenPress, that is fully functional and customized with 3D printed components and storage space. The press itself is currently one of the most prominent physical examples of student work housed in our space, and also helps to fulfill our expansion goal to incorporate more arts technologies into the lab.

Custom Graphic Designs

In another initiative to demonstrate the natural interplay

between the arts and the digital fabrication technologies in the FabLab, Morgan worked with a student employee whom he had previously taught in two studio art classes to create stylized exploded diagrams of our equipment. As a graphic design student, Priscilla Rodriguez possessed skills none of our previous employees had honed, and we sought to further develop her portfolio by having her collaborate on a design series that would be prominently displayed in the lab for years to come. During our planning for the expansion, the leadership team came to the realization that we would be moving from a situation where learners entering the space could tacitly know where various pieces of equipment were because everything was effectively right on top of everything else, to a much more spacious layout where learners might need some way finding signage to help locate or realize the existence of a desired machine. We had Priscilla start with a small series of posters to illustrate the four main machines people came to the lab to use: laser cutter, 3D printer, vinyl cutter, and mini-mill. These were received with such enthusiasm by library administration that they asked if we could create a poster for every piece of equipment in the expanded lab; Priscilla's reaction when Morgan shared admin's request is the stuff every educator lives for!

We embarked on the quest to stylistically illustrate the FabLab equipment, with every poster completed becoming our favorite, only to be unseated by the next. We experimented with different workflows, eventually finding our rhythm where Morgan would chart the course of which pieces of equipment we were going to tackle next, supply Priscilla with the manuals, and give her a walkthrough on the actual use of each machine so she would know which components were most important to the utilization of the tool in order to effectively illustrate it. We found that she worked best when she had multiple designs to work on simultaneously, and that it was best to try to ensure the various equipment in the workflow at any given time would not have too many similar design problems, allowing her to flex different aptitudes and skillsets as the machinations of any particular task grew monotonous. Meeting regularly for critique and creative direction, Priscilla and Morgan worked out the compositions that spoke to the individual personalities
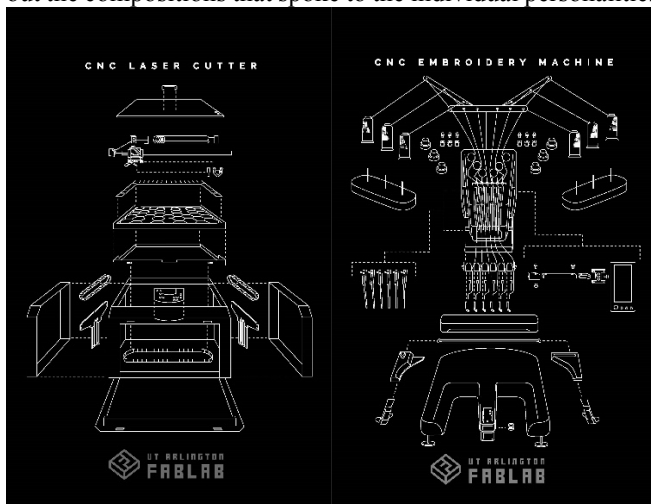

Figure 3: Two of the eighteen posters completed so far

of each machine. Eventually, it came time to put together a presentation of the set, and we were surprised by how rudimentary the initial four looked in comparison to those we had made more recently! We had refrained from displaying the initial posters until the series was completed, and quite some time had passed between the completion of the initial set and the expanded set. This stark example of how much growth had been achieved in design sensibilities and ability to describe a machine's working parts without labels over the course of the project was rewarding for everyone involved. After some reworking for cohesion as a series, those posters were declared finished, though it's tough to say the series is complete as we are always adding new machines!

Prosthetic Designs

Easily the most frustrating project we have labored over in the lab was the Quixotic undertaking to build a prosthetic for a three-legged French Mastiff who was the victim of an over-crowded puppy mill. The project had started in the summer of 2015 as a supposedly small side project introduced by administration and led by our optimistic former technician, Fraser Jones. The three technicians had a varied set of skills, with Fraser coming from a Mechanical Engineering background with modeling experience in Solidworks, Eric from Biology, and Morgan from Fine Art and Humanities. None of us knew anything about prosthetic design, and the initial results of our efforts were a demonstrable testament to that fact. Compounding the problem was that the kind souls who had rescued the dog were more eager to tell us what they thought we wanted to hear than with necessarily being accurate, so we were designing under the assumption that the dog had stopped growing. After Fraser left the FabLab to work on his PhD, Morgan stepped in to carry the conceptual 3D models to printable designs that actually interfit with one another and various hardware as intended. After preparing a prototype, we invited the dog and his owners back to the lab for a fitting, only to find he had continued to grow considerably, and the harness we had printed was already a bit beyond the recommended maximum build size of our largest 3D printer.

Serendipitously, Morgan had been a judge for an intra-campus exhibition of student research posters, where he noticed a student who won recognition for his work on 3D printing a skeletal-muscle structure of a human arm as study for prosthetic design, and promptly offered him a job. This newly-minted student employee, Adam Williams, was given the opportunity to follow his passions by immediately engaging with the prosthetic design project. In early conversations around how to revise our approach to the dog prosthetic, Adam brought up the possibility of simplifying the design problem of supporting such a large dog by abandoning the prosthetic harness & leg in favor of a cart. We initially dismissed this as that had been our first idea too, only to have had the owners tell us they had already tried a cart before contacting us. We realized at this point, however, that we had never actually seen the failed cart itself, and when we asked the owners for a photo of it, it was immediately clear why it hadn't worked – the center of gravity was way too far behind the dog's front legs! Lesson seared into our minds that

thorough information gathering at the outset of a collaborative project is crucial, Adam and Morgan got to work on a more intelligently designed prosthetic cart.

To make a long story short: we accounted for hundreds of hours of prints and a literal bin-full of ABS to work our way towards a design resilient enough to withstand the energetic movements of a 130-lb puppy. Heartbreakingly, by the time we worked up to a feasible solution, the dog was in too much pain to be cooperative and was too spooked by the spoked wheels near his head to actually use the cart.

While it is dismaying to spend so much time and effort without reaching the intended goal, we definitely learned far more from the difficulty of the design challenge than it seems we would have with a series of safely achievable projects. Given sufficient effort into significant design overhauls and committed training of the dog to use the cart, we may have been able to realize the vision of helping an abused dog live more comfortably, but we realized that level of commitment was beyond our scope, especially as it necessarily required sacrificing opportunities to work on other projects. As soon as we stopped focusing Adam's efforts on the dog prosthetic cart, we set his sights on working out a prosthetic arm for a professor's son. Shortly before the dog project began, we had registered as a partner institution with the e-NABLE Foundation[18] as a place people needing prosthetics could come to access tools to print and assemble the open-source prosthetic design files. An internal news bulletin about this partnership caught the eye of UTA Broadcast Communications professor Dr. Andrew Clark, whose seven-year-old son was born with a partial right arm that terminates just below the elbow. The various designs distributed by the e-NABLE Foundation at that time were heavily biased towards addressing the object-grasping needs of those with functional wrists; we had wanted to get involved with e-NABLE's then-ongoing beta testing and prototyping efforts for elbow-flexion prosthetics, but we had to concentrate on the dog project and hadn't had the time for both. Fortunately, when we returned to designing for humans, the e-NABLE Foundation had released two designs that allowed for elbow flexion to control digit grasping! Unfortunately, one design's forearm felt weak and was intended for use by someone with far more partial limb than our subject, while the other prosthetic was bulky, complex, and users were complaining of chafing problems.

In order to better study the potential areas for improvement in the e-NABLE design, Morgan had Adam go through the process of printing and assembling the simpler e-NABLE "Unlimbited" arm as-is, to better acclimate himself with the specifics of the design problems, and establish an early success with an opportunity to meet with the young boy and his family. After completing this, we only had a couple months until Adam graduated, though his course load was not strenuous and we were able to push for completing an overhaul of the arm with the time we had left to work together. Morgan met with Adam multiple times a week to discuss his most recent designs and any problem areas, and were able to finish the project shortly before commencement. As a bonus, we were subsequently able to hire Adam as our 4th full-time

FabLab staff member, allowing us to continue to make improvements to the design as our enthusiastic tester puts it through the real-life stresses of being an active boy's arm.

DISCUSSION

The success of our FabLab is irrevocably tethered to the work of our students, whether that is demonstrated through small acts of service as seen in the daily interactions and technical expertise they provide learners, or whether it is through larger scale, longer term projects such as those outlined here. When considering student service-learning within the context of a makerspace, it is paramount to bear in mind a few potential pitfalls, which we encountered regularly during the course of each of the five projects above: managing expectations at all levels of the institutional hierarchy when embarking on ambitious projects, the critical importance of selecting engaged partners for any interdepartmental or external cooperation[17], and the chasm between the alluring marketing of maker machines' increasingly accessible potential to empower anybody to make anything and the reality that design thinking skills are sold separately. Distilled, time management and scope creep.

The iterative design process is legitimately arduous, requiring an abundance of resilience and patience. Each of these projects was undertaken with no guarantees for success, and with no benchmark to accurately estimate the time that would be required to realize our often overly-ambitious goals. That struggle was often compounded by working with motivated students, who are more rigorously confined by the hourly limitations of their work week. In addition to the necessity of prioritizing their academic pursuits, many of our students also had to grapple with trying to balance high standards of timeliness and quality in their projects while also being bound to a finite number of work hours a week. This was counterintuitive for those students accustomed to being able to work academically for as many hours as was necessary to complete a class assignment. The FabLab Technicians also had to strike a delicate balance between delegating tasks to students in order to focus their own attentions elsewhere, and being present enough to provide appropriate levels of mentorship and constructive criticism throughout the duration of the projects.

Early successes and the siren song of ingenuity also made it easy to think about tacking on additional features and functionalities for each of these projects. With the FabApp in particular it was quickly obvious how beneficial automating our workflow would be, and appended the original goals numerous times to accommodate new ideas for other modules. We have learned to implement several strategies to prevent or postpone such scope creep, such as creating wish lists for the future, bringing in additional students to assist, or using staff meetings time to gain group consensus around reprioritizing tasks.

Despite these hurdles, the students whose projects we have highlighted in this paper have résumé gold, the FabLab has custom solutions that enhance the services we are able to offer to our learners, and we've built crucial momentum that encourages high-quality output in all subsequent student

endeavors. As this peer-leadership model continues to flourish in our space, we eagerly anticipate being able to share future examples of successful, collaborations and best practices for other academic makerspaces.

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