Shifting Expectations: Understanding Youth Employees' Handoffs in a 3D Print Shop

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As digital fabrication technology has become mainstream, the increased demand for 3D printed objects has created a new market for professional outsourcing. Given that most of this work does not require advanced training, and is an appropriate entry-level manufacturing job, there is an exciting opportunity to employ youth already skilled in "making" and interested in technology to do this work as an after-school job. The combination of this new technology and workforce calls for new workflows that streamline client-driven digital manufacturing. However, the limitations of current digital fabrication technology and youth schedules require that this work be spread between multiple shifts, necessitating employees to coordinate and handoff their work. We investigated the collaborative practices between youth employees while working on client jobs in a 3D print shop during one year of field work. In this paper, we describe instances where youth employees successfully, and unsuccessfully, handed off work between shifts and identify techniques utilized by youth to support successful handoffs, including: counting physical artifacts, using asynchronous chat programs, and documenting work. We then discuss the impact of the print shop manager's presence, physical characteristics of 3D prints, and youth perspectives of work on the selection of and effectiveness of these techniques. Finally, we offer lessons learned from successful handoffs in the print shop and recommendations for supporting youth in collaborative work environments.

CCS Concepts: • **Human-centered computing → Empirical studies in HCI**; **Computer supported cooperative work**;

Additional Key Words and Phrases: 3D printing, youth, after-school employment, workplace collaboration, shift change

ACM Reference Format:
William Easley, Foad Hamidi, Wayne G. Lutters, and Amy Hurst. 2018. Shifting Expectations: Understanding Youth Employees' Handoffs in a 3D Print Shop. *Proc. ACM Hum.-Comput. Interact.* 2, CSCW, Article 47 (November 2018), 23 pages. https://doi.org/10.1145/3274316

1 INTRODUCTION

After-school making programs are an increasingly popular way to engage youth in science, technology, engineering, and mathematics (STEM) [5]. Unfortunately, due to financial circumstances, many youth are unable to participate in these programs and instead seek out employment opportunities.

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2573-0142/2018/11-ART47 $15.00
https://doi.org/10.1145/3274316

Youth job choices can have a direct positive impact on their long-term careers [27] and provide many positive benefits including improved skills, independence, leadership, and communication [27, 30]. Despite these benefits, it is difficult for many youth to find jobs [33, 49]. The perpetually above-the-national average unemployment rate in Baltimore, Maryland (USA), the location of this project, has prompted many organizations to work to create new opportunities for its citizens [33]. Of the jobs available to youth, many are in retail or service industries and provide few opportunities for career advancement. Additionally, few rely heavily on technical skills.

Over the past several years, digital fabrication technology has become mainstream, creating a demand for 3D printing, scanning, and design services. In response, the Digital Harbor Foundation[1] (DHF), a nationally recognized educational non-profit, opened a 3D print shop staffed by youth who have completed an introductory course on making. In the year since opening, the print shop has employed eight youth as after-school shift workers. Due to the time requirements associated with completing complex orders they often must hand off their work between shifts.

In this paper, we explore the collaborative practices employed by youth in the DHF print shop. Through participant observation and interviews, both formal and informal with all stakeholders, we examined the evolution of techniques used by youth during work handoffs. We unpack five critical incidents. Through these, we identify three successful techniques: documenting work in a Google Sheet, posting status updates in Slack, and counting 3D prints left running by previous shifts. We also examine three factors which influenced the selection of and effectiveness of these handoff techniques: the print shop manager's level of involvement, the physical properties of objects being printed, and youth perspectives on work practices. Based on our findings, we offer lessons learned from successful handoffs in the print shop and recommendations for supporting youth in collaborative work environments.

2 RELATED WORK

This work builds upon and contributes to research on teenagers' use of communication technology, collaboration tools in the workplace, and youth in maker jobs.

2.1 Teenager Use of Communication Technologies

Teenagers regularly utilize a variety of mainstream communication tools – including social networks [11, 61], instant messaging [4, 10, 28], cell phones [12, 52] and video chat [16] – in their daily life. Much of the research in this area has been situated in contexts where youth spend most of their time; including at home [28] and at school [10]. Several studies have found that managing simultaneous communication channels can be time-consuming and stressful [31, 43, 59]. In a 2014 study with 12 high school teachers, Bouhnik et al. identified equitable access to smartphones, unpleasant interactions between students, and the usage of informal language (slang) as challenges to integrating WhatsApp in classroom environments [10]. There is also prior research which has looked at the communication technology use of recent graduates transitioning into the full-time workforce. In a study with 49 college students, Choi et al. [18] found that convenience (availability at home, in transit, and at work) played a major role in the adoption of new communication tools. Additionally, they found that several factors – such as shifting human networks, the desire for creating a professional persona, and the volume of communication required at work – impact communication technology choice and usage patterns. While there has been a focus on communication technology use post-college, there are approximately 3.1 million high school students in the United States with part time jobs [22]. Little is known about how this population uses work-oriented

[1] https://www.digitalharbor.org/

communication technologies, or about the potential impacts of bringing such tools into the crowded communication ecosystem that youth already manage.

2.2 Collaboration Tools in the Workspace

Scholars in the computer-supported cooperative work (CSCW) research community have long explored how technology can be used to support collaboration in the workplace. Prior investigations into the factors that make the adoption of groupware unsuccessful have found that tools often fail not because of technical problems, but instead due to a lack of understanding of the work environments they are intended to support [29]. Past research has also noted that awareness of individual and group activities is critical for successful collaborative work [23], and that communication between collaborators often occurs at the limits of transparency [21]. One domain where awareness and transparency of work activities is especially important is shift-work, where still-in-process work is frequently handed off between employees.

Prior research has described many techniques and procedures employed during handoffs in a variety of work environments. Much of this work has focused on safety-critical settings – such as hospitals [19, 25, 53, 57, 62], air traffic control [8], and space shuttle mission control [48] – where mistakes during handoffs may lead to disastrous outcomes [47]. A smaller amount of work has examined handoffs in other environments such as paper mills [6] and help desks [55]. Much of this has documented the different types of tools and approaches used to facilitate successful handoffs.

In many work environments, digital records are kept to document and track work [17, 55, 58]. During shifts, employees regularly download information from these digital records and bring them into their personal information space for manipulation [58]. Much of this manipulation occurs through the use of paper media [40, 48, 58], which can be easily adapted to support note-taking and annotation processes. During handoffs, these working documents are often exchanged between employees [40, 53, 58]. In many environments, employees that are co-located also regularly exchange information through face-to-face interaction [6, 17, 48]. Prior work has also described the use of common information spaces, such as public displays, to share high-level details about the state of ongoing work [17, 53, 58]. In a 2006 study, Wilson et al. found that introducing public displays in work environments can have a significant influence on when and how employees access information [60]. We note that the handoffs described in prior work are largely performed by highly trained and experienced individuals. Our research seeks to build on this body of knowledge through investigating how youth with limited work experience approach handoffs.

2.3 Youth and "Making"

Making is a broad term which refers to individuals performing a wide range of activities which include designing, tinkering, and building. [5]. Technological innovations in the areas of rapid prototyping – especially 3D modeling and printing – have supported this approach to learning and practice [5, 9, 38].

Previous research has demonstrated the capacity of making and project-based learning to engage youth with technical skills in a variety of environments. Examples include high schools [44], special education classrooms [13, 14], informal learning environments [51], and refugee camps [2, 56]. Scholars have studied 3D printing as a means of learning and producing creative artifacts [9, 35] and understanding accessibility challenges [15, 38]. Additionally, prior work has highlighted the benefits, implementation strategies, and technical challenges for integrating 3D printing in education [24, 26, 32, 36, 41]. Beyond the inclusion of digital fabrication tools in formal and informal learning environments, there has been a recent shift towards the creation of maker oriented jobs which offer digital fabrication as a service [5, 54]. This research contributes to an understanding of how youth use maker tools in these work environments.

3 METHODS USED TO DOCUMENT COLLABORATION IN THE PRINT SHOP

Our findings are the result of one year of field work at the DHF 3D print shop. DHF is nationally recognized educational non-profit which serves over 1,400 youth from diverse socio-economic backgrounds through after-school and summer educational programs, hackathons, and field trips. The DHF print shop was opened in January 2017 in collaboration with our university to establish a "living laboratory." Living laboratories are a user-centric approach to research which are often characterized by data collection in authentic settings [34] over an extended period [45]. Shortly after the print shop opened, we became interested in observing youth collaboration. However, this research project is multifaceted; our research group also has interests in evaluating [3, 34] software, training tools, and supporting technology.

3.1 Participants

Our investigation included stakeholders from three different roles within the print shop: 1) youth employees, 2) the print shop manager, 3) the Director of Operations of DHF. Each are described in turn.

The print shop has eight **youth employees** (Table 1) working as printing specialists who are paid hourly. These employees are between the ages of 15-18 (average age 16). All have obtained work permits and completed a 14-week course called "Maker Foundations," which is an introduction to 3D design, programming, game design and physical computing. After completing this gateway course, youth can participate in additional programs to further hone technical skills, or apply to work in the print shop. Openings in the print shop are advertised through posted flyers and recruitment emails sent to youth and their parents. Youth interested in working at the print shop must fill out an application and be interviewed by the print shop manager. Although the print shop only has eight spots, efforts are made to hire a diverse workforce.

All youth employees were introduced to 3D design tools through Maker Foundations, but had little (if any) hands-on experience with 3D printer operation and no experience with 3D scanners before starting work. DHF youth have strong computer literacy and are experienced communicating through email and accessing shared files in Google Drive[2]. Four employees (P2, P3, P4, P6) had prior experience using Slack[3] – an asynchronous chatting tool – through one of DHF's more advanced courses.

Printing specialists' main duties include printing, scanning, designing, performing quality assurance checks, and troubleshooting/resolving issues with equipment. Depending on the current workload, employees usually keep between 3-5 printers in production while working on other tasks (e.g., scanning, designing). During the school year, employee shifts last two hours (4-6 PM), and youth work 1-2 shifts per week. During the summer, youth can work up to five days a week, for five-hour shifts. Most work shifts happen concurrently with DHF's other after-school programs. Employment in the print shop is intended to be a 12-month experience and turnover is expected as youth transition into other programs/activities and graduate from high school. P1 graduated from high school six months into our study, P5 did not work at the print shop during the summer, and P4 pursued other extracurricular activities starting in the fall.

The **print shop manager** is a full-time (40 hrs/wk) staff member at DHF. He oversees day-to-day operations, assists and trains youth employees, and evaluates employee development. The manager also performs other duties within DHF which include maintaining DHF's other 3D printers (used during courses) and repairing 3D printers for local educators. He reports directly to DHF's Director of Operations.

[2]https://www.google.com/drive/
[3]https://slack.com/

Table 1. Overview of youth employee demographics and length of participation in our study.

ID	Gender	Age	Time in Study
P1	F	18	6 mos.
P2	M	17	12 mos.
P3	M	17	12 mos.
P4	M	16	9 mos.
P5	M	16	9 mos.
P6	F	15	12 mos.
P7	F	15	12 mos.
P8	F	15	12 mos.

The **Director of Operations** provides mentoring and guidance to the print shop manager. He does not typically monitor daily print shop activities, but does occasionally check on progress over extended periods by referencing records of documented work. He most frequently interacts with youth employees through Slack, or at monthly all-employee meetings.

3.2 Data Collection and Analysis

We conducted fieldwork to better understand the internal work processes of the DHF print shop. The handoff critical incidents highlighted in this paper were identified by our participant observer as worthy of deeper investigation. They were later elaborated through formal interviews and informal discussions with youth employees, and contextualized in weekly and monthly meetings. We received approval from our university's institutional review board before approaching participants. All employees and their parents consented to participating in this research, and knew that our research team was interested in understanding the opportunities and challenges in this work environment and sharing that knowledge. All interactions with participants occurred during regular work hours. Below, we describe the methods used to inform this study.

Participant Observation: We usually visited DHF three to five days per week over one year to record field notes during work shifts. Our main participant observer [42] is the first author of this paper, a doctoral student. He had over three years of prior experience with 3D printing. He was regularly accompanied to DHF by one to two other members of our research team. Our field notes covered a range of topics of interest (Table 2). These include descriptions of employee interactions with each other, with technology, and with members of our research team (to identify potential bias).

Table 2. Overview of information recorded in field notes.

Information Recorded In Field Notes	
1. Researchers present (date and time)	**6.** Employee interactions with technology
2. Employees present (date and time)	**7.** Employee interactions with DHF staff/youth
3. Jobs being worked on	**8.** Employee interactions with researchers
4. Employee interactions with each other	**9.** Barriers to successful collaboration
5. Employee interactions with clients	**10.** Strategies used to promote collaboration

While on site, we took photographs of successful and unsuccessful prints and of the work artifacts produced by youth. We also photographed the employees interacting with each other

during meetings and with clients at public events. We regularly performed member checks to confirm our observations by engaging in casual conversations with youth employees and the manager. Upon returning to our university campus from DHF, each member of our research team wrote a detailed summary of their shorthand field notes. Team members also held discussions to reflect on each day of observations. DHF's Director of Operations granted our team access to the collaborative tools used in the print shop's workflow. This included a Google Spreadsheet called the "Jobs Dashboard" and a collection of internal Slack channels. After selecting our five handoff critical incidents, we used information from these tools, and our observations, to provide rich descriptions of job requirements and youth activity during handoffs.

Weekly Meetings with Management: Our research team met with the print shop manager and DHF's director of operations for one hour each week. These meetings were used to discuss the current state of the print shop, and youth development/progress. The first author typed detailed notes during each meeting on each topic that was discussed. We used these conversations and our notes from them to inform our understanding of the work environment, and management expectations for youth.

Monthly Employee Meetings: We also participated in monthly two-hour all-employee meetings. These meetings were geared towards youth professional development and training. These helped to reveal challenges faced by youth while using Slack. Four all-employee meetings also included a one-hour group activity. Our research team lead the first three, and the fourth was led by the print shop manager. The first two activities probed employees and management to think about and define the information requirements for their workplace. The third was intended to better understand youth perspectives of work and asked employees to design a two-hour work shift, including every task that they would expect to perform. The fourth was intended to establish common ground between employees and management on what should occur during 3D printing workflows. The first author typed notes during each meeting. Artifacts produced during these activities were photographed and analyzed. Findings from the first and second activities helped to inform Section 4.4, while the third and fourth activities informed Sections 4.2 and 6.

Interviews with Youth Employees: We conducted semi-structured interviews with seven youth employees (all but P5) to contextualize our observations and hear employee perspectives on working in the print shop. Interviews were conducted six months after youth started working, lasted between 35 and 75 minutes, and were audio recorded. Interview data were fully transcribed. We then iteratively analyzed these data over two passes for information relevant to collaboration and handoffs. The first pass extracted quotes relating to communication, and the second focused on quotes coded for youth perspectives of collaborative work. Findings from these interviews provided triangulation with our participant and direct observation.

4 PRINT SHOP OVERVIEW

4.1 Print Shop Services

Since opening, the DHF print shop has manufactured over 4,000 objects, finished several large jobs including some with over 300 unique objects, and completed one complex 100-hour print. The print shop receives a combination of internal and external job requests. Internally, they handle printing for youth participating in DHF's after-school courses. Much of the external work comes from local individuals and organizations (e.g., schools and churches). The print shop has expanded its client base by also accepting job requests from their website[4] and 3D Hubs[5], an online network which connects clients to individuals and businesses with 3D printers.

[4]http://printshop.digitalharbor.org/
[5]https://www.3dhubs.com/

4.2 Print Shop Workflows and Tools

Youth employees interact with a variety of tools in their regular workflows for 3D printing, scanning, and designing. While many requests only require one of these services, some are more complex and may require a combination of tasks. To provide additional context to readers, we offer descriptions of the different workflows and tools necessary to complete them.

Table 3. Hardware and software ecosystem supporting 3D printing, scanning and design workflows

Workflow	Tools
3D Printing	**Hardware**: Atom 2.0, Dremel Ideabuilder, Flashforge Creator, Flashforge Finder, Image3D JellyBOX, Lulzbot Taz 4, Raise 3D N2 Plus, Prusa i3, Ultimaker 2 and 3. **Software**: Autodesk Print Studio, Cura, Ideamaker, Matter Control
3D Scanning	**Hardware**: NextEngine 3D Scanner. **Software**: NextEngine ScanStudio, Autodesk Meshmixer, Meshlab
3D Design	**Software**: Autodesk Tinkercad, Autodesk Fusion
Collaboration	**Software**: Google Calendar, Google Docs, Google Sheets, Gmail, Slack, 3D Hubs

3D Printing Workflow: The most frequent requests received by the print shop are to print objects in plastic filament. If a digital model, typically a .STL (stereolithography) file, is provided by the client, the first stage of the printing process involves *slicing* the model into layers/instructions (commands and coordinates in space known as *G-Code*) for the printer to follow. During the slicing process, the printer operator selects printer and material-specific settings which will determine the physical properties and quality of the finished product. After slicing an object, the G-Code is transferred to a 3D printer using USB, Wi-fi, or an SD card. If the print is successful, the item is removed from the print bed and then checked for flaws during a quality assurance check. If it does not pass inspection, it is re-printed.

3D Scanning Workflow: The print shop occasionally receives requests to scan physical objects so that they can be reproduced. Before an object can be scanned, the operator must first configure the scanning software to capture the object at an appropriate level of detail. Next, the operator may need to take additional steps to prepare the object for scanning. For example, they may need to coat the object with chalk if it has a reflective surface or mark the object with unique stickers if its shape has few distinguishing features. The object must then be placed at the correct distance from the scanner (e.g., 17 inches) for best results. After completing a scan in a specific orientation, the operator must assess its quality and decide if additional scans at different orientations are needed to fully capture the object (e.g., placing the object on its side to capture the bottom). After scanning is complete, the operator must prepare the scan(s) for 3D printing. This process includes aligning and merging completed scans into one mesh, removing unwanted artifacts, digitally smoothing out imperfections, filling unwanted holes left in the object, and exporting the scanned object as a .STL file.

3D Design Workflow: Designing custom objects is the most complicated type of job in the print shop, but also the least common. To initiate a custom design, a client will typically contact the print shop with a description of their desired object along with as many details as possible about their request (e.g., intended function and size/dimensions of object). A print shop employee will then use this information to design a prototype in computer-aided design (CAD) software. Depending on the specificity of the request (e.g., need for dimensional accuracy), multiple design

iterations and sustained communication with a client may be necessary. Some of the key challenges and activities in designing a unique object are to fully understand the client's vision for the object (e.g., dimensions, shape, function) and selecting appropriate design tool(s).

4.3 3D Printing Technology Constraints and Challenges

Despite the increasing popularity and accessibility of 3D printing technology, there are still a number of challenges that even skilled operators must manage. For example, printers are relatively slow and can fail for a number of reasons including issues with the .STL file, printer calibration, environmental conditions, or manufacturing defects with plastic filament [1]. 3D scanners are similarly impacted by environmental conditions, require a computer with a powerful GPU to render models, and are not tolerant of user errors (e.g., orientation of object in physical space). Most modern 3D design tools have a steep learning curve due to reliance on very specific terminology. Managing failed prints and scans can be very time consuming and frustrating, and are one reason why some clients prefer to outsource this work. However, it is important to note that these challenges can create tension between the client and print shop if they impact a job's timeline.

4.4 Collaborative Tools Used To Support Handoffs

Given the size of most client jobs and that youth work in relatively short shifts, it is common for employees to collaborate on client jobs that span across multiple shifts. Thus, employees must *handoff* information to their coworkers about tasks that are in progress, have been attempted but not completed, or finished. These handoffs usually occur asynchronously across successive days. The print shop has adopted two software tools to support information exchange: a "Jobs Dashboard" created in Google Sheets, and a collection of Slack channels. These tools were selected by the management (the print shop manager and the Director of Operations) because they resemble tools commonly used on modern technical teams.

4.4.1 The Jobs Dashboard. The Jobs Dashboard was designed by the DHF to resemble the enterprise-level job tracking ticketing systems commonly used in customer support and software development. Since this tool was developed in-house, management had the ability to adapt the design to meet the print shop's specific information requirements. During the study period this tool underwent two major revisions.

When the print shop receives a new job, it is first reviewed to determine whether it is feasible or not. If the job is accepted, it is given a job ID (e.g., 147) and added to the dashboard along with a link to a corresponding Google Drive folder with .STL files. This process also consists of adding a row to the overview tab of the dashboard (Figure 1A), and creating a new tab for that specific job (Figure 1B). Each row of the overview tab of the dashboard contains: a unique job ID and name, a brief description of the job (e.g., "Raspberry Pi Cases"), the client's name, the overall job status (e.g., printing, ready for pickup), and the deadline.

4.4.2 Slack Stand Up Meetings. Since opening, the print shop has used Slack as a primary communication and coordination tool. Slack has grown significantly in popularity over recent years and now has over eight million daily users [50]. Print shop employees can access Slack on their work computers and are also encouraged to install the application on their personal smartphones. The management have encouraged youth to socialize on Slack, sharing interesting digital fabrication news, updates on the status of their work, and jokes. For the purposes of this paper we focus our analysis on one Slack channel called "printshop-standup," which was introduced eight months into our study as a structured way to facilitate the sharing of status updates during handoffs. At the end of each shift, youth employees post to this channel indicating if they updated the Jobs Dashboard or worked on any tasks that were not tracked. Youth also share what jobs were left running on

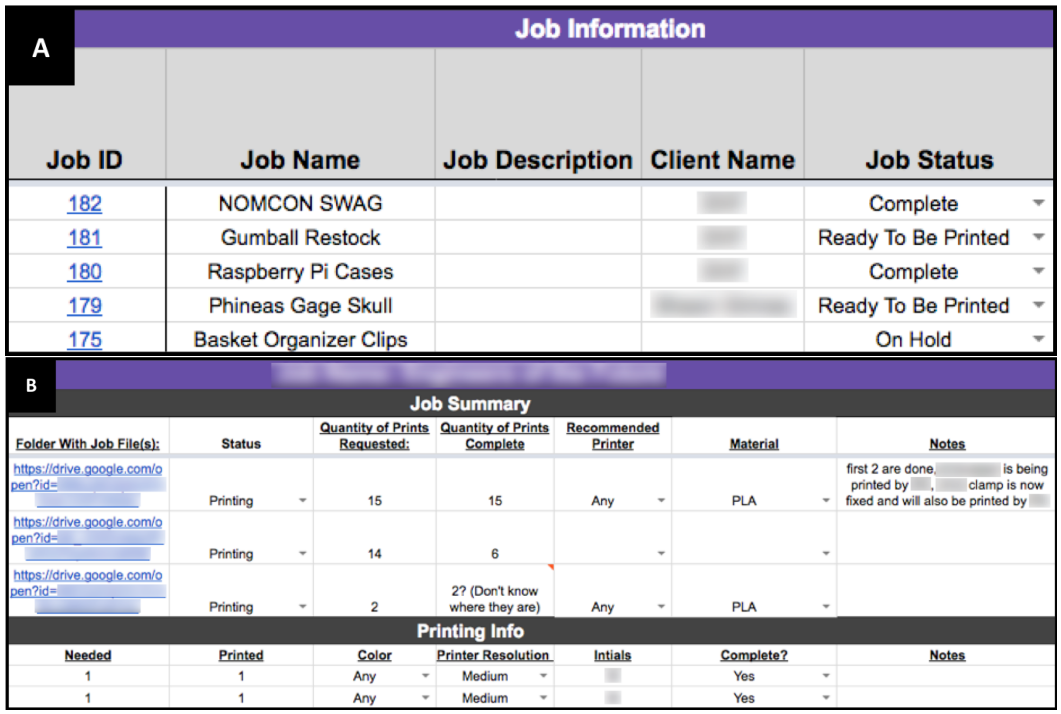

Fig. 1. The Jobs Dashboard consisted of a overview tab that gave an overview of current jobs (A). Each job had its own tab with details about each file to be printed (B).

the printers, along with any other updates for the incoming shifts. Stand ups were initiated by an automated application called Geekbot[6].

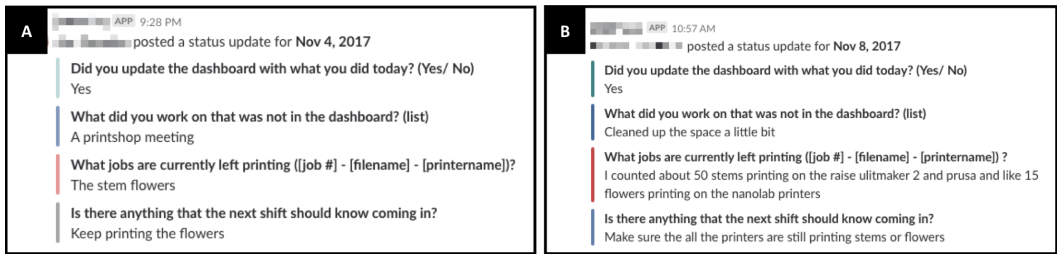

Fig. 2. Two examples of stand ups posted on Slack. Note the difference in detail between both responses.

5 UNPACKING SUCCESSFUL AND UNSUCCESSFUL HANDOFFS

During one year of observation, we identified three techniques used by employees during handoffs. We also found that the manager's level of involvement with a job and the physical characteristics of 3D prints influenced the selection and effectiveness of these handoff techniques. We describe below instances where youth employees successfully and unsuccessfully handed off work between shifts. For each example, we provide descriptions of the initial job requirements and handoff techniques

[6]https://geekbot.io/

used to coordinate the work. We also offer an explanation of the factors contributing to the success or failure of handoffs. We summarize the job requirements, level of manager involvement, 3D print characteristics, and the handoff techniques utilized by youth employees in each example in Table 4 to accentuate the differences between each job. In Section 5.3 we offer lessons learned from these successful handoffs.

Table 4. A summary of handoff techniques used by employees, 3D print characteristics, and level of manager involvement across multiple jobs. The columns distinguish between successful and unsuccessful handoff examples.

	Successful Handoffs			**Unsuccessful Handoffs**	
	Martin Luther	Camp	Flowers	Ladder	Assistive Device
Job Requirements:					
Received Printable File	Yes	Yes	Yes	Yes	No
Num. of Prints Needed	7	94	340	1	27
Num. of .STL Files	3	94	3	1	16
Print Characteristics:					
Print Length (Hours)	20 - 120	.5 - 1	1.5 - 13.5	8	1 - 7
Recognizable Object(s)	Yes	No	Yes	No	No
Manager Involvement:					
Manager Set Up Dashboard	Yes	Yes	Yes	Yes	No
Manager Present	Yes	Yes	Partial	No	Partial
Handoff Techniques:					
Num. of Slack Updates	6	0	17	2	0
Dashboard Updated	No	Yes	Yes	No	No
Count Finished Prints	Yes	No	Yes	No	No

5.1 Unpacking Successful Handoffs

We observed instances where youth employees counted finished prints (Example 1: Martin Luther statues), documented work via the dashboard (Example 2: summer camp prints), and coordinated work over Slack (Example 3: flowers and vases) in support of successful handoffs. During our time on site, we observed multiple instances of these behaviors, but selected three examples to illustrate each of these practices. We will later contrast these with examples of unsuccessful handoffs.

5.1.1 Example 1: Martin Luther Statues. In our first example, the pastor of a local church requested that seven statues of Martin Luther, the 15th century theologian and reformer, (Figure 3 A and B) be printed in white filament (Table 4) using three different .STL files. Each file took approximately 20, 24, and 120 hours to print, respectively. Due to the lengths of these prints, this job was completed gradually over approximately two months. To support the youth employees working on this job, the manager updated the dashboard to include links to the files, and the quantity and color of prints requested for each file. In addition to adding this job to the dashboard, he sliced all three .STL files and left a note in the dashboard stating that ready-to-print files were already loaded on the Raise 3D printer's SD card.

We observed that youth employees successfully handed off their work without relying extensively on either of the print shop's collaboration tools. While the original job request was added to the

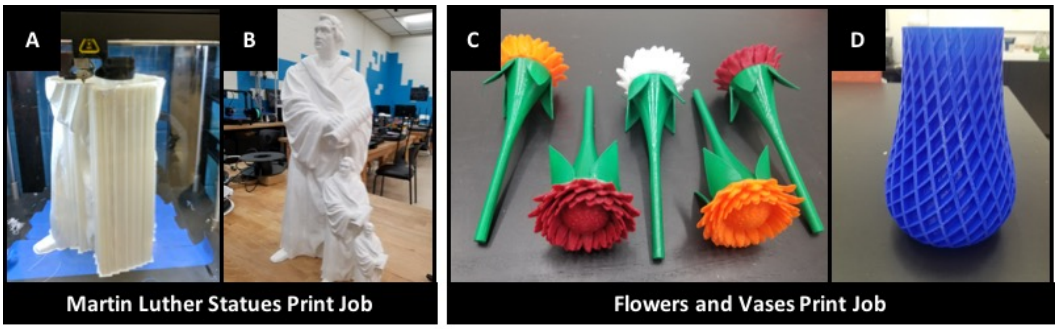

Fig. 3. Prints completed for the Martin Luther (A,B) , and flowers/vases jobs (C,D).

dashboard, no progress updates or records of completed prints were kept. In addition, three employees shared status updates on Slack on six occasions. Rather than heavily utilizing the Jobs Dashboard and Slack to coordinate work, we found that youth employees could instead manually count the number of completed prints in order to determine what work remained.

We believe that the simplicity of this request (few parameters to track), high recognizability of requested prints, and high level of manager involvement were all contributing factors towards successful handoffs. While handoffs were necessitated by the length of prints, employees working across shifts had no problems differentiating these statues from prints for other ongoing jobs or determining what work remained. The manager personally set up the dashboard and sliced the 3D models for printing, ensuring youth had all of the resources needed to be successful. The manager was also present throughout the duration of this job and able to monitor progress, help youth prioritize work, and provide technical guidance when necessary.

5.1.2 Example 2: Summer Camp Prints. In our second example, the print shop was asked to fabricate 94 unique designs created by students attending an engineering summer camp. Each design took between thirty minutes and one hour to print. To support the youth employees working on this job, the manager added this job to the dashboard, including links to all of the .STL files and instructions to print each file once in whatever color was available. This job was completed in phases, with additional prints being added over time. However, the bulk of this printing was completed in approximately one week.

We observed that four print shop employees and the manager were heavily engaged in keeping the dashboard up to date. After each print was finished, it was marked complete, along with the initials of the employee who printed it. In instances where files were not printable, brief notes were left describing the error. The print shop's dedicated stand-up channel did not yet exist on Slack when this job was completed. However, no status updates about this job were initiated by youth in other channels.

Unlike the Martin Luther job, youth employees were heavily engaged with the Jobs Dashboard. We believe that the complexity of this request rendered the technique of manually counting prints ineffective. With a one week turnaround time, the dashboard was needed to track each item separately so that work would not be repeated. Prints, on average, took less than two hours to finish, making it possible for employees to document the completion of each print. In addition to setting up the dashboard and ensuring that youth had access to all 94 files, the manager contributed directly to printing files and modeled expected behaviors for updating the dashboard. Some job details, such as descriptions of print failures, were not recorded during any other job presented in this paper, and were rarely documented during our time on site.

5.1.3 Example 3: Flowers and Vases. In our final example of success, the print shop received a request to create 20 centerpieces to be displayed during a roundtable discussion for educators in Maryland. The centerpieces were to be comprised of 3D printed vases with flowers. This job required 160 flower stems to be printed in green filament, 160 flowers with petals to be printed in orange, white, and maroon filaments, and 20 vases (designed by the manager) to be printed in blue filament. The stems and flowers were then attached together and distributed evenly between the vases. Overall, this job required 340 prints to be completed, from three different files. The manager, who was on a business trip during part of this job, added this request to the dashboard. Five youth employees contributed to this job over approximately one month.

In this example, employees used both the dashboard and Slack to monitor and exchange information. The dashboard was used to track the number of required and completed petals (separated by color), stems, and vases. It was also used to track the number of assembled flowers arranged in vases. Due to the large number of required prints, printers were left running between shifts. Youth posted stand up responses on Slack on 17 occasions, letting the incoming shift know that prints were left running. We noted that responses provided varying levels of detail. P2, for example often provided detailed updates (Figure 2B) which included the number of prints and names of printers left running. However, most stand up responses were not this detailed (Figure 2A) and incoming shifts would still have to physically count completed prints.

All of the successful strategies used in our previous examples were repeated here. Similar to the summer camp job, most of the required prints (flowers and stems) could be fabricated during a 2-hour shift and marked complete in the dashboard. When printers were left running at the end of shifts, employees used Slack to share updates. While most of these updates were not very descriptive, all prints for this job were recognizable enough that incoming shifts were able to identify and count completed prints, and then update the dashboard accordingly.

5.2 Unpacking Unsuccessful Handoffs

While the handoff techniques described above helped complete many significant jobs, we observed instances of jobs where employees struggled to successfully share information across shifts. We describe two examples below where handoff techniques were either unsuccessful (Example 4, ladder) or not employed at all (Example 5, assistive devices). We selected these two jobs because they were among the most severe examples of communication challenges in the print shop. We describe the requirements and context of each job, the attempted handoff techniques, and discuss factors contributing to these unsuccessful handoffs.

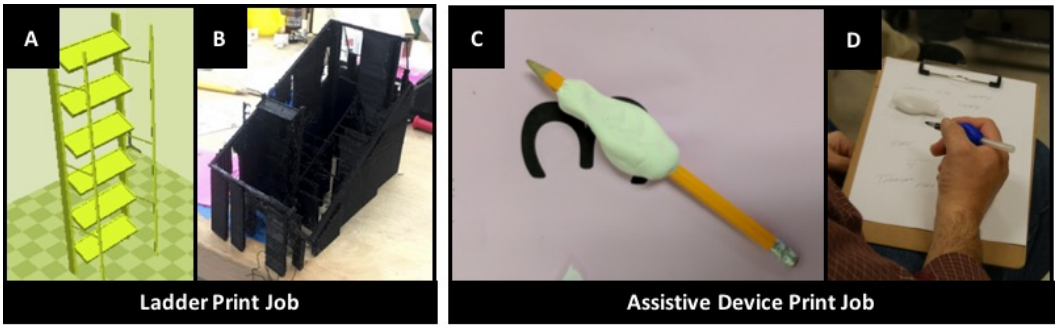

Fig. 4. Prints completed for the ladder (A,B) and assistive device jobs (C,D).

5.2.1 Example 4: Ladder. The print shop received a request on 3D Hubs to produce one 3D printed copy of a ladder (Figure 4A). The manager first attempted to print this file but was unsuccessful. He informed the client of the failed print and received an updated file, referred to as ladder (V2). In preparation for their upcoming one week vacation, they added this job to the dashboard (linking only to the .STL file for ladder V2), and left behind a list of prioritized tasks in a Google Doc (not the dashboard) for employees to work on. This job, with a due date on Tuesday, was given a high priority and assigned to P8, who works on Mondays. In total, three employees were involved with this job over a one week period and multiple unsuccessful copies of the original ladder file were attempted (Figure 4B). Ultimately, this job request was withdrawn, and the business of a paying customer was lost. We describe a timeline of major events and communication breakdowns between shifts that contributed to unsuccessful handoffs and job completion.

Mon. An early closure announcement email goes out from DHF's Operations Manager notifying employees that they should come into work two hours early. P8, who was assigned this job does not read the schedule change email in time and decides to report for work on Tuesday instead. P2, was present at the print shop, but was not sure if they should work on this job since it was assigned to P8. Instead they work on one of the lower priority jobs.

Tue. P8 reports to work and starts printing a pre-sliced file that was already loaded on a printer in the shop, believing it be the correct file for the job. However, this turns out to be the faulty file (ladder-V1) that the manager had previously attempted to print. The print is not complete at the end of the two-hour shift so P8 messages P2 on Slack asking if he can contact the client letting them know that their job will be complete on Wednesday.

Wed. P2 checks the completed print and remarks to our observer that something does not look right. He tries printing it again using the same pre-sliced file that P8 printed the day before, and does not leave any notes for future shifts.

Thu. Only P4 is present at work. He checks the dashboard, but does not find any notes from earlier shifts about this job. He mentions that he is unsure of what the final object is supposed to look like. He direct messages P8 on Slack for help but does not hear back during his shift, and posts a picture of the failed print in the general channel. He then checks both the dashboard and 3D Hubs in an attempt to determine how the final print should look. He locates both the correct (in the dashboard) and incorrect (in 3D Hubs) .STL files and is unsure how to proceed. When asked about this experience during his interview, P4 said *"...[I] just really had no idea what to do...people at the beginning of the week had just been printing [the ladder] over and over again, and it was kind of hard to reach them."* (P4)

Fri. Three employees, including P4 are at work. P4 continues trying to figure out what is needed for this job, but eventually gives up, leaving this problem for the manager to resolve on Monday.

We attribute the struggles encountered during this job to four factors: the manager's absence, difficulty identifying what the completed print should look like, not documenting work in the dashboard, and unresponsiveness on Slack. While this job only had one item to track, it was similar to the Martin Luther statues because the requested print took over two hours to complete. Like in previous examples, in-progress prints were not noted in the dashboard. We observed that P4 was not able to determine how the finished print should look because the model was almost entirely covered in automatically generated support structure[7] (a slicer setting) and rotated 90 degrees on the print bed. Without notes or responses from colleagues on Slack, P4 was left in the dark. Finally, without the manager present, simple mistakes were not identified early on and persisted throughout the week.

[7]https://www.3dhubs.com/knowledge-base/supports-3d-printing-technology-overview#fdm

5.2.2 Example 5: Assistive Devices. In our final example, the print shop was tasked with producing 12 custom 3D printed assistive devices for older adults. These devices were designed by 12 groups of physical therapy students at a nearby medical school as part of a class project. Rather than receiving digital files ready for printing, the print shop received clay models that were to be scanned and turned into .STL files. Each assistive device design was accompanied by an order form describing the objects' intended function, dimensions, and desired physical properties (e.g., printer filament preferences). Some clay models arrived in multiple parts and needed to be scanned, printed and then assembled. Others needed to be scanned, modified in CAD software (e.g., add a hole to an object), and then printed. Additionally, a few parts needed to be designed from scratch based on dimensions and drawings provided by the clients. In total 27 prints were required for this job from 17 unique files. This job occurred concurrently with the ladder prints, and the manager was on vacation during the first week of this job. The print shop originally had one and a half months to complete this job. Unfortunately, this request was never added to the Jobs Dashboard and the original deadline was not met. We will only focus on factors contributing to the original missed deadline, but note that changes were later made – including the introduction of Slack stand ups – which helped contribute to the eventual completion of this request. During the month and a half leading up to this deadline, four youth employees worked on this job.

None of the handoff techniques identified in this paper were employed before this job's original deadline. Because the clients did not provide any files for printing, the print shop was responsible for creating them. Both methods used to create printable files, 3D scanning and 3D design, are time intensive and often iterative processes. Work was not often finished during shifts and status updates were rarely shared among colleagues. We observed that youth employees would start designs in CAD software, but not share progress updates or links to their design files at the end of their shifts. When they were not at work, progress on that design would either stall, or be restarted by someone else. When designs were complete, they were exported as .STL files and uploaded to Google Drive. Without access to the original design files, we found that some designs needing revisions were re-created from scratch. During scanning, we observed on several instances that employees within and across shifts would re-scan objects from the same angle. We also observed that some scans were unsuccessful because objects were placed too far from the scanner. On several occasions, the print shop experienced data loss due to the scanner software crashing under heavy load. This problem was later to attributed to a combination of the scanning computer's insufficient hardware configuration, and the order in which certain actions were performed in the software during the scanning workflow. Descriptions of these challenges were not frequently shared between shifts and these problems persisted throughout the duration of this job. Finally, models which were not properly polished in the scanning software often had rough surfaces (from leftover scanning artifacts) or holes (from areas the scanner could not detect) and had to be re-polished and re-printed.

In this example, print shop employees rarely shared updates on their progress or handed off work to their peers despite the complexity of the job. With a mix of scanning, designing, and printing work, each assistive device was essentially a separate job requiring one or more custom prints that, with a few exceptions (e.g., a pencil grip), were not recognizable to most employees. Without the manager's presence at the start of this job, a full description of the work was never entered into the dashboard. Employees quickly lost track of when this job was due, favoring other work instead. When the manager did return to work, he intentionally took more of a hands-off approach to promote youth independence. With limited oversight, small but detrimental mistakes, such as placing an object too far from the scanner, were not quickly caught or addressed, and often resulted in youth having nothing to show for their efforts. During an all-employee meeting, youth revealed that there was considerable confusion over what work was already done, and how to share files and information.

5.3 Lessons Learned from Successful Handoffs

Many digital fabrication workflows – such as slicing a .STL file or setting up a 3D scan – are not inherently collaborative. These multi-step workflows are most often initiated and carried out by only one individual. Many potential mistakes, such as selecting a slicing profile with too much support (Example 4), or placing an object too far from the scanner (Example 5), can occur and lead to confusion for incoming shifts. A challenge within this space is that few auditory or visual affordances exist which support the peripheral awareness that allows employees to catch each other's mistakes when they occur [40]. We offer three recommendations on how to promote successful handoffs in digital fabrication environments.

5.3.1 Break Down of Complex Jobs. The jobs received by the printshop had a wide range of complexity. This complexity is not necessarily reflected in metrics such as the number of .STL files that needs to be printed for each job. For example, in the case of the assistive device job (Example 5), each of the 17 unique objects needed to be individually scanned or designed before being manufactured and assembled. In a way, this job could be thought of as 17 separate jobs, each requiring a complex set of steps for completion. Dividing these complex jobs in a way that can be more easily approached by youth employees, for example as clear sets of tasks that can be easily documented, might be a useful strategy. This would require the implementation of additional documentation practices – such as developing consistent naming conventions to refer to different components of a job – in order to successfully support coordination.

5.3.2 Document Low-level Procedures. In print shops and similar fabrication environments, a record of steps taken or software settings can be used to help repeat a process or fix a problem. The print shop's implementation of both the Jobs Dashboard and Slack channel place an emphasis on high-level details of work. While both tools contain information that is helpful in tracking overall progress, neither is used to track small, granular details. When workflows (such as the scanning in Example 4) fail or are left incomplete, incoming employees are left with very few useful pieces of information. This results in wasteful, redundant work as they need to backtrack and recreate to make sense of the current state of the job. Details, such as slicer or scanner settings exist only in the mind of one solitary employee. Prior work has demonstrated the value of employees keeping and passing along notes during shift changes [6, 40]).

We believe that the implementation of work practices or systems which encourage youth to record and leave behind notes – detailing steps taken during printing, scanning, design, and troubleshooting workflows – may help to improve the visibility of important low-level details. Possible ways to implement note-taking practices in the print shop include the introduction of checklists (paper or digital) or an unstructured journaling mechanism. We note however, that there may not be one perfect solution but instead an ecology of practices that fit specific jobs and personal work styles.

5.3.3 Promote Group Awareness of Important High-level Details. We found that youth employees lost track of the deadline for the assistive device job (Example 5) and began prioritizing other work. We believe that print shops and other similar environments can benefit from having better or more visible mechanisms to share important information such as deadlines and work assignments [58]. Access to this information on a public display may remove some of the clutter found in documentation tools (like the dashboard) and help to support youth in making their own decisions about how to select and prioritize work. Another exciting direction is to use these common information spaces to display the operating status of equipment through the implementation of more "sociable" tools as described in [39].

6 YOUTH PERSPECTIVES ON WORKFLOWS AND HANDOFF TECHNIQUES

As mentioned in Section 3, we conducted four group activities during all-employee meetings to better understand how youth employees thought about and defined their work responsibilities. In this section we refer to findings from the third and fourth design activities, notes taken during regular all-employee meetings, and our one-on-one interviews with youth employees. In Section 6.4 we offer recommendations for supporting youth in collaborative work environments.

6.1 Interacting with a Manager

Youth employees felt that the manager, who is typically present at DHF every day (through successive shifts), played a key role in assigning and prioritizing tasks (P4, P6), and resolving confusion (P4). His continued presence in the print shop also helped to compensate for many communication breakdowns between employees. P6, for example, could not recall encountering any challenges during handoffs because the manager was always present to help her figure out what needed to be done.

> *"Communication breakdowns? not really…I come in, [the manager] tells me what I'm supposed to do, I get my computer out I start working…"* (P6)

We note that in an ideal situation, youth employees should be able to refer to information from the Jobs Dashboard and Slack stand-ups to determine what to work on during their shifts. P4 described being often unsure of what to do when coming into work. They similarly noted that the manager was able to resolve this confusion.

> *"There are a lot of times when I come in, and I'm not exactly sure what to do, but…I can ask [the manager] and he can tell me…"* (P4)

Finally, during an all-employee meeting, they discussed why the deadline for the assistive device job was not met. Youth explained that they had expected the manager to add this job to the dashboard. The manager however, explained that he expected employees to be able to perform this task independently; especially during his absence.

The manager played a significant role in the youth employees' transition into the workplace. He provided professional mentoring, technical assistance, and an introduction to the collaborative tools and processes needed for work. During daily operation, he regularly added new jobs to the dashboard (Examples 1-3), helped employees resolve communication breakdowns and find tasks to work on, and in some cases contributed directly towards the completion of print jobs (Examples 2 and 3). Unintended effects of this high level of involvement were two-fold. Like other work environments, the print shop encourages youth to work through problems independently or with colleagues before escalating them to a supervisor. However, youth employees reached a point where they were comfortable approaching their manager for assistance first. Youth also eventually developed the expectation that their manager would always perform administrative tasks such as adding new jobs to the dashboard (Example 5). This expectation did not align with the manager's view that youth employees would eventually take over these tasks as he transitioned to a more realistic supervisory capacity.

6.2 Documenting Work

We gained insight into the employees' view of when to document work in the third group activity when we asked youth to describe everything that should occur during a two-hour shift. While all youth included many small tasks (e.g., signing into computers) in their lists, only one employee mentioned updating the dashboard or posting updates to Slack as part of their regular activities. Additionally, only one youth mentioned face-to-face updates with a collocated colleague as a regular work activity.

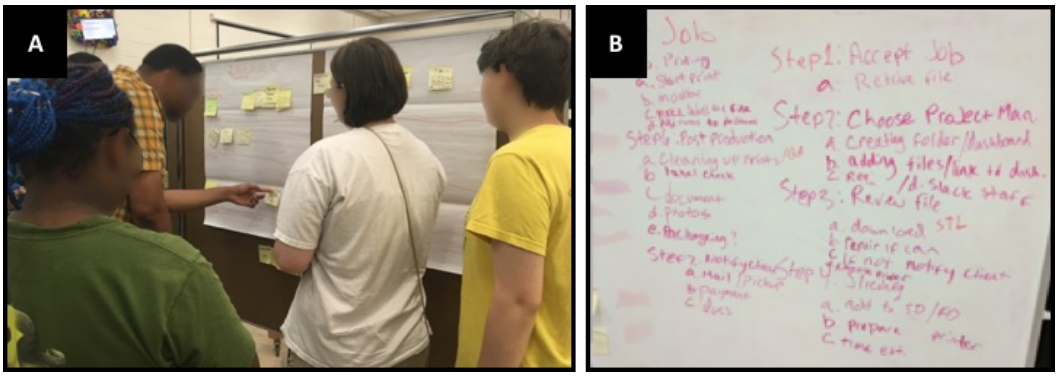

Fig. 5. Youth during a researcher-led activity where they listed all of the tasks that should be performed during a work shift, and placed them in two hour a schedule (A). The mutually agreed upon 3D printing workflow defined by youth employees and management (B).

In the fourth group activity, youth worked together with management to define an ideal 3D printing workflow (Figure 5). We again observed that documentation was considered by youth to be a "post production" task, which would occur after prints were successfully completed. Recall that 3D printing, due to technical limitations, is a time-consuming activity with non-trivial failure rates (Section 4.3). During his interview, P4 explained that a major source of confusion during the ladder print job was due to prints not being finished during previous shifts.

> *"...they didn't communicate with the person who came [in] the next day...it was a large print, so it took longer than the person was working to get [it] done, so the next day, there was this big black thing there and nobody really knew what it was..."* (P4)

Over time, youth employees developed their own strategies on when to document work. The youth perspective that work should only be documented once completed often resulted in work left undocumented at the end of shifts. This perspective was also contrary to management's view that all work should be tracked in process. Youth were willing to do extra work to overcome this, such as having to count – as many as hundreds of – finished prints, and consult with their manager for progress updates. While these practices are commendable, show dedication and engagement to work, they were not the best use of their time and would not be necessary if all stakeholders reached a common understanding on when documentation should occur.

6.3 Communicating Using Slack

We observed that youth encountered some challenges while adjusting to Slack. Among the most prevalent were stand-ups being posted late (or missed) and long response times (Example 5). During an all employee meeting, employees revealed that many stand up responses were posted late because they were waiting to receive a prompt from Geekbot. We believe that these missed reminders were the result of some Slack accounts being accidentally set to an incorrect time zone. In response to missed stand-ups, management regularly encouraged youth to make stand ups part of their regular schedule. Below is a reminder posted by DHF's director of operations on Slack.

> *"As a heads up for everyone, if for whatever reason you don't get a standup prompt, please post an update before you leave anyway. This will 1) help the team that comes in behind you and 2) shows that you are proactive..."* (DHF Director of Operations)

During our interviews, youth also explained that logging into Slack was a tedious process. P2, who had prior experience with Slack remained logged in on his computer at home, but did not always log in at work because others would forget to sign out of their accounts on the print shop's work computers. P7, who was new to Slack described issues with remaining logged into Slack on her phone.

> *"Slack will always sign me out once I exit the app… that's annoying sometimes because I can never tell when people are contacting me or what's going on on Slack unless I actually physically log in which is an annoyance because it takes longer online."* (P7)

Unlike the Jobs Dashboard, Slack is not designed in-house. While it can be customized through 3rd party integrations, management has limited power to fundamentally change the way that this tool works. The print shop, like other professional organizations, considers using and being available on communication tools to be a work responsibility. As such, youth employees were expected to overcome any challenges configuring and accessing Slack in order to be effective employees.

6.4 Recommendations for Supporting Youth in Collaborative Work Environments

In this section, we offer a series of recommendations on how to support youth in 3D fabrication environments and other sites where asynchronous, collaborative technical work is performed. Here, we advocate for a mix of technical and social interventions.

6.4.1 Empower Youth Employees to Work with Limited Manager Intervention. We found that high levels of manager intervention were common, even as youth became more experienced in their roles (Section 6.1). We recommend that the role of managers should be dynamically defined such that their relationship with youth employees transitions from a hands-on role in the beginning to one that is supportive in a more hands-off manner. This transition should be transparent and youth should be made aware of expectations for them to become more self-reliant. One possible way to promote independence may be to encourage youth to regularly perform administrative tasks (e.g., adding new jobs to the dashboard). Gradually shifting these responsibilities from managers to youth may help to promote accountability and ownership of work. Missed deadlines, such as the assistive device job, can also be valuable learning experiences which help to show the importance of collaboration. We note that one challenge which may always exist in these environments is the tension between providing a safe learning environment where mistakes can be made, and operating a business where deadlines must be met and mistakes have real economic consequences.

6.4.2 Understand Youth Perspectives of Work. We found that youth developed their own expectations for how and when work should be documented (Section 6.2). We believe that it is important for managers to understand this in order to avoid potential conflicts. If the perspectives of youth do not align with those of managers, then expectations should be clearly communicated (or collaboratively defined with employees). Possible ways to communicate these expectations include providing training on how collaborative tools should be used and through modeling expected behaviors [37] when possible (Example 3). Finally, occasional reminders similar to the one from DHF's Director of Operation in Section 6.3 may be helpful in supporting youth to form new habits.

6.4.3 Expose Youth to Current Workplace Communication Tools. Synchronous and asynchronous communication awareness is an integral part of the modern workplace. We believe that early exposure to popular communication tools, such as Slack, may prove to be a valuable source of experience for youth to draw from when they enter the full-time workforce. Beyond learning how these tools work, this exposure may help youth to better understand employer and customer

expectations. Lastly, this provides them with opportunities to learn about and practice professional etiquette.

6.4.4 Scaffold Collaborative Tasks. To make documentation practices more accessible to inexperienced employees, the print shop made both the Jobs Dashboard and Slack stand-ups structured. While this structure helped youth to organize and present their thoughts, it may not be appropriate as a long-term solution. When youth enter the workforce full-time, they will likely to encounter many types of unstructured collaborative interactions. For example, Youth may engage in handoffs in a variety of settings/contexts [17, 58], encounter documentation systems which require open ended descriptions of work [55], or have the responsibility of preparing reports or presentations.

We found that stand-up responses were not always filled out with sufficient details (Example 3). During the early stages of scaffolding, it is important to correct early mistakes. As youth become more experienced, it may be worth considering a shift away from structured collaborative tasks, or adding additional mechanisms which encourage them to share unstructured updates (e.g., through speaking at meetings). Additionally, it may be valuable to encourage more peer-to-peer interaction/feedback in instances where documentation is found to be lacking. This may be especially valuable during activities such as collaborative troubleshooting which are highly reliant on establishing a common understanding of technical details [6, 55].

7 DISCUSSION

To be successful in the print shop, youth must master the technical aspects of operating the tools and equipment necessary for the printing, scanning, and design workflows, but also many communication, coordination, and collaboration skills. Unfortunately, these skills are rarely foregrounded in STEM education, leaving students at a loss in environments that require them.

Consider that the print shop's employees are new to the workforce and have had limited opportunities to practice and develop advanced collaborative skills. For example, as part of their work responsibilities, they are asked to asynchronously hand off work to colleagues with whom they rarely interact. This type of interdependent work differs significantly from youth employees' past experiences in classrooms, or even in other after-school settings where collaboration typically occurs face-to-face. As work becomes more oriented towards geographically diverse teams [46], we believe that it is valuable to provide youth with opportunities to gain experience functioning within these environments.

For the youth employees, the shift from learners to professionals involved a change in perceptions and attitudes towards communication and collaboration that their new job roles required. In addition to learning new tools and procedures, the youth had to figure out how to relate to each other in a new way, not as friends, classmates or siblings but as colleagues. Further, this shift needed to be reflected in the way they communicate with each other for job tasks to be completed effectively. While learning how to use new communication tools was a challenge, equally important was learning what to communicate, to whom, and when.

In this sense, we found that documenting low-level procedures and raising employee awareness towards high level logistical details were both needed to help the youth reflect on what is important in a technical workplace and needs to be communicated with others. Faced with the challenge of figuring out what needs to be done and how, the employees sought out strategies, such as depending on the manager or only utilizing 3D printers that they had experience with to simplify their work experience and turn complex jobs into more manageable tasks. While these strategies were effective in the short term, they proved inadequate for complex tasks. These findings emphasize the need to develop effective scaffolding strategies to support the youth in the transition from informal learning to technical employment.

Even though we observed several instances of unsuccessful handoffs and communication breakdowns, we observed that youth employees improved on their collaboration skills over time. Specifically, they began to appreciate the need to spend time documenting work and communicating with the next shift. We find this trend encouraging and believe that adopting our recommendations can lead to them developing these skills faster. However, we also note that in some ways, there is no singular technical or social fix to the challenges described in this paper. Instead, a sociotechnical fix is required in which new norms are appropriated by the workplace and supported (not inhibited) by the tools in use.

8 FUTURE WORK

Our site provided unique, longitudinal access to young employees just entering the technical workforce. This allowed us to witness transformations within individuals, the organization, and their technical infrastructure. Fieldwork such as this provides deep insight illuminated through a single case. While the results may not be directly generalizable, this insight is transferable to similar production settings which are collaborative in nature [7, 20] and susceptible to similar communication breakdowns and bottlenecks [20]. It can inform sociotechnical interventions to improve collaborative performance in the workplace. While it was not a focus of the original research, this insight into shifting expectations of work has driven us to explore the transitions students face moving from the structured, co-located, tightly managed environments of their education to the often under-structured, asynchronous, and loosely managed technical jobs of the future gig-economy. Finding new ways of fostering effective interdependence among virtual teams will be key to their success.

We are also interested in exploring a better integration of social media skills in the workplace. As born-digital workers, our employees had digital awareness technologies well integrated into their daily lives. They knew exactly what their friends were up to by following their moment-by-moment Instagram feeds, Facebook updates, and tweets. This natural ability to always be aware of others did not translate naturally to the office where the Jobs Dashboard and Slack stand-ups seemed foreign and unnatural, when, fundamentally, they were nearly identical. How then can the distributed teams of the future better leverage the naturally developed technical skills for peripheral social awareness that new employees already have mastered to be more effective at coordinating in the workplace? Our deep partnership with DHF will allow us to continue this investigation into the future.

ACKNOWLEDGMENTS

We would like to thank our participants and collaborators at the Digital Harbor Foundation for their insight. We thank Mark Minnis and Pavan Konanur for their help with data collection. Finally, we would like to thank our reviewers for their valuable feedback. This material is based on work supported by the National Science Foundation under Grant No. EEC-1623490.

REFERENCES

[1] 2013. Print Troubleshooting Pictorial Guide - RepRapWiki. (2013). https://reprap.org/wiki/Print_Troubleshooting_Pictorial_Guide Accessed: 2017-09-18.

[2] Konstantin Aal, George Yerousis, Kai Schubert, Dominik Hornung, Oliver Stickel, and Volker Wulf. 2014. Come_in@Palestine: Adapting a German Computer Club Concept to a Palestinian Refugee Camp. In *Proceedings of the 5th ACM International Conference on Collaboration Across Boundaries: Culture, Distance & Technology (CABS '14)*. ACM, New York, NY, USA, 111–120. https://doi.org/10.1145/2631488.2631498

[3] G. D. Abowd. 1999. Classroom 2000: An Experiment with the Instrumentation of a Living Educational Environment. *IBM Syst. J.* 38, 4 (Dec. 1999), 508–530. https://doi.org/10.1147/sj.384.0508

[4] Murugan Anandarajan, Maliha Zaman, Qizhi Dai, and Bay Arinze. 2010. Generation Y adoption of instant messaging: An examination of the impact of social usefulness and media richness on use richness. *IEEE Transactions on Professional Communication* 53, 2 (2010), 132–143.

[5] Chris Anderson. 2012. *Makers: The New Industrial revolution.* Crown Business. 257 pages.

[6] Esa Auramäki, Mike Robinson, Ann Aaltonen, Mikko Kovalainen, Arja Liinamaa, and Taina Tuuna-Väiskä. 1996. Paperwork at 78Kph. In *Proceedings of the 1996 ACM Conference on Computer Supported Cooperative Work (CSCW '96).* ACM, New York, NY, USA, 370–379. https://doi.org/10.1145/240080.240348

[7] Andrew Begel and Beth Simon. 2008. Novice Software Developers, All over Again. In *Proceedings of the Fourth International Workshop on Computing Education Research (ICER '08).* ACM, New York, NY, USA, 3–14. https://doi.org/10.1145/1404520.1404522

[8] Richard Bentley, John A Hughes, David Randall, Tom Rodden, Peter Sawyer, Dan Shapiro, and Ian Sommerville. 1992. Ethnographically-informed systems design for air traffic control. In *Proceedings of the 1992 ACM conference on Computer-supported cooperative work.* ACM, 123–129.

[9] Paulo Blikstein and Dennis Krannich. 2013. The makers' movement and FabLabs in education: experiences, technologies, and research. In *Proceedings of the 12th international conference on interaction design and children.* ACM, 613–616.

[10] Dan Bouhnik and Mor Deshen. 2014. WhatsApp goes to school: Mobile instant messaging between teachers and students. *Journal of Information Technology Education: Research* 13, 1 (2014), 217–231.

[11] Danah Boyd. 2014. *It's complicated: The social lives of networked teens.* Yale University Press.

[12] J Alison Bryant, Ashley Sanders-Jackson, and Amber MK Smallwood. 2006. IMing, text messaging, and adolescent social networks. *Journal of Computer-Mediated Communication* 11, 2 (2006), 577–592.

[13] Erin Buehler, William Easley, Samantha McDonald, Niara Comrie, and Amy Hurst. 2015. Inclusion and Education: 3D Printing for Integrated Classrooms. In *Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility - ASSETS '15.* ACM Press, New York, New York, USA, 281–290. https://doi.org/10.1145/2700648.2809844

[14] Erin Buehler, William Easley, Amy Poole, and Amy Hurst. 2016. Accessibility Barriers to Online Education for Young Adults with Intellectual Disabilities. In *Proceedings of the 13th Web for All Conference (W4A '16).* ACM, New York, NY, USA, Article 27, 10 pages. https://doi.org/10.1145/2899475.2899481

[15] Erin Buehler, Shaun K Kane, and Amy Hurst. 2014. ABC and 3D: opportunities and obstacles to 3D printing in special education environments. In *Proceedings of the 16th international ACM SIGACCESS conference on Computers & accessibility.* ACM, 107–114.

[16] Tatiana Buhler, Carman Neustaedter, and Serena Hillman. 2013. How and why teenagers use video chat. In *Proceedings of the 2013 conference on Computer supported cooperative work.* ACM, 759–768.

[17] Yunan Chen. 2011. You've Covered: Designing for In-shift Handoffs in Medical Practice. In *Human-Computer Interaction – INTERACT 2011*, Pedro Campos, Nicholas Graham, Joaquim Jorge, Nuno Nunes, Philippe Palanque, and Marco Winckler (Eds.). Springer Berlin Heidelberg, Berlin, Heidelberg, 541–558.

[18] David Choi, Judy Chen, Stephanie Wu, Debra Lauterbach, and Aruna Balakrishnan. 2015. From Dorms to Cubicles: How Recent Graduates Communicate. In *System Sciences (HICSS), 2015 48th Hawaii International Conference on.* IEEE, 2013–2022.

[19] Michael D Cohen and P Brian Hilligoss. 2010. The published literature on handoffs in hospitals: deficiencies identified in an extensive review. *Quality and Safety in Health Care* (2010), qshc–2009.

[20] Bill Curtis, Herb Krasner, and Neil Iscoe. 1988. A Field Study of the Software Design Process for Large Systems. *Commun. ACM* 31, 11 (Nov. 1988), 1268–1287. https://doi.org/10.1145/50087.50089

[21] Laura Dabbish, Colleen Stuart, Jason Tsay, and Jim Herbsleb. 2012. Social Coding in GitHub: Transparency and Collaboration in an Open Software Repository. In *Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work (CSCW '12).* ACM, New York, NY, USA, 1277–1286. https://doi.org/10.1145/2145204.2145396

[22] Jessica Davis. 2012. School Enrollment and Work Status: 2011. *American Community Survey Briefs* (2012), 4.

[23] Paul Dourish and Victoria Bellotti. 1992. Awareness and Coordination in Shared Workspaces. *Proc. Intl. Conf. on Computer-Supported Cooperative Work* November (1992), 107–114.

[24] William Easley, Erin Buehler, Gabrielle Salib, and Amy Hurst. 2017. Fabricating Engagement: Benefits and Challenges of Using 3D Printing to Engage Underrepresented Students in STEM Learning. In *2017 ASEE Annual Conference & Exposition.*

[25] Daniel Flemming and Ursula Hübner. 2013. How to improve change of shift handovers and collaborative grounding and what role does the electronic patient record system play? Results of a systematic literature review. *International journal of medical informatics* 82, 7 (2013), 580–592.

[26] Jim Flowers and Matt Moniz. 2002. Rapid prototyping in technology education: rapid prototyping, while costly, can afford students a unique opportunity to bring their ideas to reality. *The Technology Teacher* 62, 3 (2002), 7–12.

[27] Alexander Gelber, Adam Isen, and Judd B Kessler. 2014. *The effects of youth employment: Evidence from new york city summer youth employment program lotteries.* Technical Report.

[28] Rebecca E Grinter and Leysia Palen. 2002. Instant messaging in teen life. In *Proceedings of the 2002 ACM conference on Computer supported cooperative work*. ACM, 21–30.
[29] Jonathan Grudin. 1994. Groupware and social dynamics: eight challenges for developers. (1994), 92–105 pages. https://doi.org/10.1145/175222.175230
[30] Georgia Hall, Laura Israel, and Joyce Shortt. 2004. *It's About Time! A Look at Out-of-School Time for Urban Teens*. Technical Report. National Institute on Out-of-School Time. https://www.niost.org/pdf/AOLTW.pdf
[31] Jeffrey A Hall and Nancy K Baym. 2012. Calling and texting (too much): Mobile maintenance expectations,(over) dependence, entrapment, and friendship satisfaction. *New media & society* 14, 2 (2012), 316–331.
[32] Erica Rosenfeld Halverson and Kimberly Sheridan. 2014. The maker movement in education. *Harvard Educational Review* 84, 4 (2014), 495–504.
[33] Job Opportunities Task Force and Associated Black Charities. 2010. *Expanding Baltimore's Black Middle Class: Workforce Strategies for Advancing Prosperity*. Technical Report. http://www.jotf.org/Portals/0/ExpandingBaltimoresBlackMiddleClass.pdf
[34] Cory D. Kidd, Robert Orr, Gregory D. Abowd, Christopher G. Atkeson, Irfan A. Essa, Blair MacIntyre, Elizabeth D. Mynatt, Thad Starner, and Wendy Newstetter. 1999. The Aware Home: A Living Laboratory for Ubiquitous Computing Research. In *Proceedings of the Second International Workshop on Cooperative Buildings, Integrating Information, Organization, and Architecture (CoBuild '99)*. Springer-Verlag, London, UK, UK, 191–198. http://dl.acm.org/citation.cfm?id=645969.674887
[35] Vasilis Kostakis, Vasilis Niaros, and Christos Giotitsas. 2015. Open source 3D printing as a means of learning: An educational experiment in two high schools in Greece. *Telematics and Informatics* 32, 1 (feb 2015), 118–128. https://doi.org/10.1016/j.tele.2014.05.001
[36] Dennis Krannich, Bernard Robben, and Sabrina Wilske. 2012. Digital fabrication for educational contexts. In *Proceedings of the 11th International Conference on Interaction Design and Children*. ACM, 375–376.
[37] Jean Lave and Etienne Wenger. 1991. *Situated learning: Legitimate peripheral participation*. Cambridge university press.
[38] Ben Leduc-Mills, Jaymes Dec, and John Schimmel. 2013. Evaluating Accessibility in Fabrication Tools for Children. In *Proceedings of the 12th International Conference on Interaction Design and Children (IDC '13)*. ACM, New York, NY, USA, 617–620. https://doi.org/10.1145/2485760.2485882
[39] Thomas Ludwig, Alexander Boden, and Volkmar Pipek. 2017. 3D Printers As Sociable Technologies: Taking Appropriation Infrastructures to the Internet of Things. *ACM Trans. Comput.-Hum. Interact.* 24, 2, Article 17 (April 2017), 28 pages. https://doi.org/10.1145/3007205
[40] Wendy E. MacKay. 1999. Is Paper Safer? The Role of Paper Flight Strips in Air Traffic Control. *ACM Trans. Comput.-Hum. Interact.* 6, 4 (Dec. 1999), 311–340. https://doi.org/10.1145/331490.331491
[41] Lee Martin and Colin Dixon. 2013. Youth conceptions of making and the Maker Movement. In *Interaction Design and Children Conference, New York*.
[42] Sharan B Merriam. 2009. *Qualitative research: a guide to design and implementation* (2nd ed.). San Franscisco.
[43] Paul Mihailidis. 2014. A tethered generation: Exploring the role of mobile phones in the daily life of young people. *Mobile Media & Communication* 2, 1 (2014), 58–72.
[44] Selena Nemorin. 2015. A critical perspective on 'Making' in school: The implementation of 3D printing in high-school settings. In *FabLearn Conference*.
[45] Corinna Ogonowski, Benedikt Ley, Jan Hess, Lin Wan, and Volker Wulf. 2013. Designing for the Living Room: Long-term User Involvement in a Living Lab. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '13)*. ACM, New York, NY, USA, 1539–1548. https://doi.org/10.1145/2470654.2466205
[46] Gary M Olson and Judith S Olson. 2000. Distance Matters. *Hum.-Comput. Interact.* 15, 2 (sep 2000), 139–178. https://doi.org/10.1207/S15327051HCI1523_4
[47] Emily S Patterson, Emilie M Roth, David D Woods, Renée Chow, and José Orlando Gomes. 2004. Handoff strategies in settings with high consequences for failure: lessons for health care operations. *International Journal for Quality in Health Care* 16, 2 (2004), 125–132.
[48] Emily S Patterson and David D Woods. 2001. Shift changes, updates, and the on-call architecture in space shuttle mission control. *Computer Supported Cooperative Work (CSCW)* 10, 3 (2001), 317–346.
[49] Andrea Payne. 2009. *A Young Workforce At Risk: Reconnecting Out-of-School and Out-of-Work Youth in Maryland*. Technical Report. http://www.jotf.org/Portals/0/IssueBrief-AYoungWorkforceAtRisk.pdf
[50] Becky Peterson. [n. d.]. Slack has 8 million daily active users - Business Insider. ([n. d.]). http://www.businessinsider.com/slack-8-million-users-ipo-2018-5 Accessed: 2018-06-28.
[51] Irene Posch and Geraldine Fitzpatrick. 2012. First steps in the FabLab: experiences engaging children. In *Proceedings of the 24th Australian Computer-Human Interaction Conference*. ACM, 497–500.

[52] Ahmad Rahmati and Lin Zhong. 2013. Studying smartphone usage: Lessons from a four-month field study. *IEEE Transactions on Mobile Computing* 12, 7 (2013), 1417–1427.

[53] Rebecca Randell, Stephanie Wilson, Peter Woodward, and Julia Galliers. 2010. Beyond handover: supporting awareness for continuous coverage. *Cognition, Technology & Work* 12, 4 (2010), 271–283.

[54] Thierry Rayna and Ludmila Striukova. 2016. From rapid prototyping to home fabrication: How 3D printing is changing business model innovation. *Technological Forecasting and Social Change* 102 (2016), 214–224.

[55] Nikhil Sharma. 2008. Sensemaking handoff: when and how? *Proceedings of the Association for Information Science and Technology* 45, 1 (2008), 1–12.

[56] Oliver Stickel, Dominik Hornung, Konstantin Aal, Markus Rohde, and Volker Wulf. 2015. 3D Printing with Marginalized Children—An Exploration in a Palestinian Refugee Camp. In *ECSCW 2015: Proceedings of the 14th European Conference on Computer Supported Cooperative Work, 19-23 September 2015, Oslo, Norway*, Nina Boulus-Rødje, Gunnar Ellingsen, Tone Bratteteig, Margunn Aanestad, and Pernille Bjørn (Eds.). Springer International Publishing, Cham, 83–102.

[57] Allan Stisen and Nervo Verdezoto. 2017. Clinical and Non-Clinical Handovers: Designing for Critical Moments. In *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing*. Association for Computing Machinery (ACM), 2166–2178. https://doi.org/10.1145/2998181.2998333

[58] Charlotte Tang and Sheelagh Carpendale. 2007. An Observational Study on Information Flow During Nurses' Shift Change. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '07)*. ACM, New York, NY, USA, 219–228. https://doi.org/10.1145/1240624.1240661

[59] Sherry Turkle. 2008. 10 Always-On/Always-On-You: The Tethered Self. *Handbook of mobile communication studies* (2008), 121.

[60] Stephanie Wilson, Julia Galliers, and James Fone. 2006. Not All Sharing is Equal: The Impact of a Large Display on Small Group Collaborative Work. In *Proceedings of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work (CSCW '06)*. ACM, New York, NY, USA, 25–28. https://doi.org/10.1145/1180875.1180880

[61] Pamela Wisniewski, Haiyan Jia, Heng Xu, Mary Beth Rosson, and John M Carroll. 2015. Preventative vs. reactive: How parental mediation influences teens' social media privacy behaviors. In *Proceedings of the 18th ACM Conference on Computer Supported Cooperative Work & Social Computing*. ACM, 302–316.

[62] Xiaomu Zhou, Mark S Ackerman, and Kai Zheng. 2009. I just don't know why it's gone: maintaining informal information use in inpatient care. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 2061–2070.

Received April 2018; revised July 2018; accepted September 2018