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Transforming academic machine shops for approachability and equity: Identity resources for learning and participation in traditionally masculine spaces

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Abstract

Academic machine shops provide important learning resources for undergraduate engineering students. However, their association with historical masculine norms and technical authority often excludes the participation of students whose identities do not align with this culture. This study addresses these approachability challenges by investigating how machine shops can be intentionally redesigned to encourage the participation of students with diverse identities. The research focused on the machine shops in two institutions in New England, both of which were going through redesign efforts to create a more welcoming and inclusive atmosphere. Data were collected through focus groups with 34 engineering students across both campuses, alongside interviews with faculty members central to the redesign efforts. Guided by the theoretical framework of practice-linked identities and identity resources, we identified ideational, material, and relational resources that are present or absent in the two shops to shape students' learning and participation. Finally, we propose actionable strategies for institutions to cultivate these resources and promote equitable participation in academic machine shops.

Introduction

This work-in-progress study is motivated by the first author's experience as both a graduate teaching assistant at a university machine shop and a scholar in engineering education. She frequently heard students describe the shop as "intimidating," especially from students with traditionally marginalized identities in engineering (students who are not white or Asian men). This sentiment led many to avoid the space until they were required to use it for their senior capstone projects, despite the valuable learning resources it offers. Although the Department of Mechanical Engineering recognizes this issue and seeks to create a more welcoming environment, shifting the long-standing masculine narrative of machine shops remains a significant challenge. These challenges inspired the present study, which aims to understand how academic machine shops can be transformed to ensure approachability and equity.

We studied two institutions where the academic machine shops are undergoing reforms to address approachability and equity. We conducted focus groups with 34 students to understand their perceptions of their machine shops, and interviewed the faculty members leading these reform efforts to better understand their motivations and challenges. Drawing on the theoretical frameworks of *practice-linked identities* [1] and *identity resources* [2], we aim to identify resources that machine shops can offer to support student participation. In this work-in-progress paper, we share preliminary results and discuss how these findings can translate into actionable strategies for making machine shops more welcoming.

Background

Academic machine shops are learning spaces that offer not only the digital fabrication tools found in makerspaces but also heavy machinery such as mills, lathes, and Computer Numerical Control (CNC) equipment. Typically embedded within university engineering departments, these shops serve as sites for students to learn design, prototyping, and manufacturing. Machine shops have a long history in engineering education. In the 1800s, engineering students spent significant time completing apprenticeships on the shop floor [3]. Entering the 1900s, however, the curriculum shifted toward engineering science, reducing shop time in favor of theoretical knowledge and understanding. During this period, student roles shifted from manufacturing with their own hands to specifying designs for professional technicians to fabricate and focus on testing and analysis [3, 4]. Recently, there has been a renewed emphasis on design skills and industry readiness. Machine shops have re-emerged as vital spaces for engaging students in hands-on learning, teaching them the practical possibilities and constraints of manufacturing to better prepare them for the workforce [5]. Recognizing this value, many engineering programs are now actively integrating making pedagogies and machine shop experiences into their curricula.

Despite their growing recognition as critical learning resources for undergraduate engineering students, machine shops present significant approachability barriers. The heavy machinery inside the shops presents an intimidating appearance and poses safety risks, which frequently deter novice users from engaging [6]. Furthermore, these spaces have been historically associated with manufacturing shop floors, which were dominated by men and excluded the participation of people with other gendered identities [7, 8, 9]. Modern academic machine shops focus on education rather than industrial manufacturing. However, the historical narratives of the shop floor, coupled with an engineering culture dominated by white or Asian middle-class able-bodied men continue to create an unwelcoming and an unapproachable environment for students with other identities, whether it is related to class, race, gender, or other characteristics [10, 11, 12].

To address the approachability challenges in machine shops, we looked at how similar issues are addressed in the design of makerspaces, which feature more prominently in engineering education research. Makerspaces gained popularity in the early 2000s as these environments "democratize STEM education" by providing young people access to digital fabrication tools such as 3D printers and laser cutters, which support hands-on STEM learning [13, 14]. Makerspaces have since expanded across secondary and higher education and are now frequently integrated into undergraduate engineering curricula [15, 16].
However, research indicates that despite the promise, makerspaces continue to attract white or Asian middle-class able-bodied men, who have been dominant in the traditional STEM fields [17]. The culture of makerspaces often perpetuates technocentric narratives within engineering and technology. Despite making is an activity deeply rooted in human's lives and take many diverse forms, making that is associated with technical and economic values tend to be more prioritized in makerspaces over making that is related to caregiving and family values [18, 19]. As a result, students from backgrounds that are historically underrepresented in STEM or those who do not feel their identities align with the technocentric narratives can view makerspaces as uninviting and inapproachable [20, 21, 22].

Numerous studies have further characterized these barriers to approachability in makerspaces and proposed potential solutions. For instance, Schauer et al. highlighted that makerspaces are more inaccessible and inapproachable for women than men. In makerspaces, men are often associated with serious or high-stakes activities such as woodworking, while women are linked to casual or fun activities like crafting. Such stereotyping impedes women's self-efficacy with certain technical tools [21]. Furthermore, the physical infrastructure of makerspaces are often ergonomically unfriendly for women, with the worktables often designed to be too high, and the "one-size-fit-all" personal protective equipment often does not fit for women [7]. These findings align with broader literature suggesting that makerspaces can reinforce technocentric narratives, creating barriers to women's participation [18], [19]. Moreover, through a survey study, Andrews et al. (2021) provided further quantitative evidence that makerspaces can be less approachable for certain students groups [23]. Beyond gender disparities, students who identify as international, multiracial, or Black experience less of a sense of belonging than their peers in a makerspace, underscoring a significant racialized gap within makerspaces.

To address these barriers to approachability, researchers have proposed various solutions and interventions. Schauer et al. advocate for modifying the physical design of makerspaces to ensure that the tools and workstations are ergonomically friendly for women [21]. Complementing the physical changes, Tomko et al. recommend creating apprenticeship opportunities that allow women to mentor women in makerspaces [24]. Furthermore, Wigner et al. emphasize that training staff on best practices for diversity and inclusion, along with active outreach through identity-based student organizations, can foster greater engagement among students traditionally underrepresented in STEM [25]. Finally, to counteract prevailing technocentric narratives, scholarship suggests legitimizing broader forms of making, such as arts and crafts, and projects that address family or community needs, to create a more culturally inclusive environment [19, 24, 26].

Although literature on makerspaces offers an essential starting point for addressing inclusivity and approachability in making-centered education, academic machine shops present a unique set of complexities. Machine shops' higher-stakes machinery and their historical ties to exclusionary industrial practices can intensify the barriers documented in makerspace research. This study contributes to the limited literature on academic machine shops, and investigates the barriers in machine shops that hinder the participation of students with historically underrepresented identities in STEM. By identifying these obstacles, this research seeks to propose pedagogical interventions and structural improvements designed to transform machine shops from intimidating, historically-exclusive sites into equitable and approachable learning environments for all engineering students.

Theoretical Framework

Our study is guided by the theoretical frameworks of *practice-linked identities* and *identity resource*s [1, 2]. The theory of *practice-linked identity* posits that the sense of connection a student feels toward a specific setting shapes how they perceive their identity within that space. This perception, in turn, directly influences their engagement and learning. Therefore, a student's connection to a machine shop determines the extent to which their identity is validated and how deeply they engage with learning in that space. Learning environments provide or fail to provide *identity resources* for students to form this connection. These identity resources are categorized as ideational (ideas that determine what is worthy to be learned), material (the physical environment and artifacts available for learning), and relational (interpersonal interactions and mentorship that support learning), all of which collectively shape student learning and identity development in a learning environment.

In this work-in-progress study, we investigate the identity resources that machine shops provide or fail to provide to support students in developing strong practice-linked identities, which can encourage their engagement with the shops. This study addresses these approachability challenges by investigating how machine shops can be intentionally redesigned to provide identity resources and encourage the participation of students with diverse identities.

Method

This research focuses on machine shops at two universities in New England, both of which are undertaking redesign efforts to create a more welcoming and inclusive atmosphere. Institution A is a medium-sized R1 research university. Its machine shop is funded by the Department of Mechanical Engineering (ME) but remains open to all university students and faculty. However, it serves as a primary pedagogical hub for the approximately 400 undergraduate ME students, who are required to complete lab-based coursework and projects within the shop. The shop has a long history, with a vintage aesthetic and older machinery. Institution B is a small, teaching-focused college specializing in undergraduate engineering. With a total enrollment of approximately 400 students university-wide, the machine shop is deeply integrated into the core curriculum for all students, regardless of their major. Unlike the historical feel of Institution A, this shop features a modern aesthetic equipped with newer machinery.

During the summer of 2025, we conducted an IRB-approved study involving focus groups with 34 engineering students across both institutions to understand their learning experiences within these shops. The focus groups, conducted by the first and second authors, consisted of two to four students each and lasted between 30 and 60 minutes. These sessions were semi-structured, utilizing a set of core questions (listed in Appendix 1) with follow-up questions for clarification.

Student demographics including year of study, major and gender are summarized in Appendix 2. Although racial identity data were also collected via open-ended responses, we have omitted these specific markers from the current summary to protect participant confidentiality. A dedicated, intersectional analysis of these qualitative racial identity markers is currently underway and will be presented in future work to ensure these lived experiences are represented with the rigor and depth.

At Institution A, we recruited 23 participants, specifically targeting Mechanical Engineering (ME) and Human Factors Engineering (HFE) majors. This selection was intentional, as these students are academically required to utilize the shop for coursework and projects, and so their engineering identities are closely tied to their participation in the shop. This group included 22 undergraduates and 1 Master's student from the institution's 4+1 program; the latter was included because she had been in the undergraduate program until recently and she had the perspective as a student staff member. At Institution B, we recruited 11 participants from across all engineering majors because the curriculum at Institution B integrates machine shop engagement as a universal requirement for all students, regardless of their specific discipline. Across both sites, four participants from each institution served as student staff. The smaller sample size at Institution B relative to Institution A was primarily due to the smaller overall student population present on campus during the summer data collection period. Crucially, thematic saturation was reached within these 11 interviews, as participant responses began to yield consistent patterns and recurring insights regarding their experiences in the shop. We therefore believe this sample offers a representative cross-section of the student experience at Institution B, providing sufficient depth for the comparative goals of this inquiry. Additionally, we interviewed one faculty member from each institution who is central to the redesign initiatives.

Preliminary data analysis presented in this work-in-progress draws upon post-session debriefs among the authors. The first and second authors had reflective discussions after each focus group and interview, and had weekly discussions with the third author. Through this process, we identified emerging examples of the three categories of identity resources (ideational, material, and relational), and logged quotes from the focus groups to illustrate these examples. The scope of this work-in-progress paper is to present at least one illustrative example for each of the three categories of identity resources.

Future work will involve transcribing and coding the full dataset with the three categories of identity resources. By mapping participant narratives to the ideational, material, and relational framework, we aim to systematically analyze students' lived experiences in the machine shop. Furthermore, we will cross-reference these codes with student demographics to explore how identities intersect with how specific resources that facilitate engagement and how the lack of specific resources hinder participation.

Findings: Identity Resources in the Two Machine Shops

In this section, we provide one identity resource from each category: ideational, material, and relational resources. We present students' quotes to better illustrate and contextualize the resources.

Ideational resources: Shop-organized training sessions on the usage of machines

Both institutions offer training sessions designed to teach students how to use specific machines. These training sessions provide critical ideational resources by demonstrating machine capabilities, allowing students to ideate and conceptualize personally meaningful artifacts and learn through the design and fabrication process. However, the delivery of these sessions differs significantly, particularly regarding the registration process and the scaffolding of skill development. These structural differences shape the effectiveness of these training sessions as an ideational resource.

To sign up for training sessions, at Institution A, students need to submit an online form indicating which machine they want to be trained on and their general availability, then wait for staff to follow up to coordinate a specific time. In contrast, Institution B maintains a fixed weekly schedule for each machine (e.g., manual mill training every Tuesday at 3:00 PM), allowing students to self-register for established slots. The open-ended nature of Institution A's process appears to create a psychological barrier, with many students postponing registration for training despite a desire to participate. For instance, Amelia, a third year student at Institution A, said:

> *"I just need to do my Red Zone training, truthfully, like I just, I haven't found a good time to do the like, the lathe and the mill training. And I just… I know I need to do it."*

At Institution A, the "Red Zone" houses heavy machinery, such as manual mills and lathes. Amelia aspired to learn all the equipment in the shop before graduation, but never enrolled in a course that explicitly required Red Zone usage. Consequently, when compounded by the stress of other coursework, the effort required to navigate the open-ended sign-up process became a barrier, leading her to consistently deprioritize the training. She also seems to feel a sense of guilt for the deprioritization. Institution B's sign-up structure may reduce participation barriers by decreasing administrative back-and-forth email exchanges needed to schedule training. The fixed schedule also allows for spontaneous decisions to attend; if one student decides to go, they can easily invite a peer who happens to be available to join them.

The learning experience during training is also different across institutions, especially in how skill development is scaffolded. Students in Institution A receive a one-off training on each machine, while at Institution B, the students are provided with multiple levels of training on each machine to advance their skills. For example, for the manual mill, students at Institution A are considered ready to use the machine on their own after receiving a 1.5-hour one-off training. In contrast, students at Institution B can choose to receive a series of training on the manual mill, with level 1 about simple machining techniques, and when they demonstrate their competency for level 1, they can schedule a training in level 2, which teaches them more advanced skills with the machine. This provides more bite-sized learning modules, making the learning more approachable.

At Institution A, some students expressed anxiety about feeling ill-equipped to operate heavy machinery after a single training session. Oliver, a third year Human Factors Engineering student, said:

> *"[...] Red Zone training stuff. But there's also a part of me that's like, nervous, because I know it's like a long training and they're dangerous machines, and I feel like I'm scared that I would like get trained, but then, like, not take everything in and still not feel comfortable, like going to use those machines, so that's definitely kind of made me hesitate."*

Oliver's hesitation highlights the cognitive overload and fear associated with a condensed 1.5-hour training, particularly when dealing with heavy-duty and high-risk equipment. Furthermore, although the shop staff members are supportive, Institution A lacks a formal structure for guided practice or review after the training, which could be supported if this training were accompanied by a project in the curriculum. Without a mechanism to reinforce these skills immediately, students risk forgetting critical safety details, leading to continued discomfort and avoidance. In contrast, Institution B's scaffolded structure breaks the information into manageable, incremental stages. This allows students to fully grasp the skills in level 1, build confidence through facilitated practice, and then advance to acquire more complex techniques. Students at Institution B seem more comfortable in using heavy-duty machines after training.

Material resources: Support for learning through personal projects

Besides coursework, we noticed that many students at both institutions learn to use machines by creating personal projects that are meaningful to them. However, it costs money for the students to purchase materials for their personal projects. At institution A, Elijah, a second-year Mechanical Engineering student, leveraged his connection to receive funding from the Robotics Club to make an electric scooter. He recounted the challenging experience in securing the funding:

> *"[...] students had a lot of questions about how to even get started with a personal project because it feels so out of reach for them.[...] I had to like, go to clubs, ask for funding, and, you know, make plans and talk to [name of a faculty member] about certain things. And it was a lot of legwork just to be able to even have the materials available for me to use."*

Because purchasing parts and materials poses a significant financial burden, a lack of funding opportunities presents a major hurdle at Institution A for personal projects. Elijah described the necessity of leveraging personal networks to seek out funding, citing the absence of an official, transparent infrastructure. It creates inequity because students in better financial situations can afford to learn through making personal projects, while others cannot. Similarly, one's belonging to the dominant social groups may provide more social capital towards this end. One notable resource to this inequity, however, is the abundant availability of scrap materials at Institution A. Students are welcome to use the scrap materials for free for their coursework and personal projects.

In contrast, Institution B has an initiative called "Passionate Pursuits," which funds students' personal projects. If a student proposes their project with a concrete plan and a list of materials they need, they will be funded up to $200 to complete the project. The students at Institution B seem to be engaging with a wide range of topics through the "Passionate Pursuits," and many purchase materials for making artifacts in the machine shop. Abby, a second-year Mechanical Engineering student, shared:

> *"Many students, like, apply every semester, because we all have, like, just like, super cool things that we want to, like, learn and do. [...] I've heard a bunch of people be like, I want to make a bike that, like, the steering is reversed, which is, I tried, it was very hard to ride. Book binding is another one. There's like, research on, like, the microstructure of various, like, animal bones. "*

As evidenced by what Abby expressed, this mechanism truly nurtured students' creativity and intrinsic motivation to pursue projects in a wide range of topics. This strengthens their machine shop skills, which they can then apply through their formal coursework. Formal support structures like "Passionate Pursuits" provide students with the essential financial means to access material resources. By covering the costs of materials, the institution ensures that the opportunity to engage in personalized learning is equitable and approachable to all students. This allows the machine shop to serve as a hub for diverse, student-driven inquiries.

Relational resources: Personal connections at the shops

Students at both institutions consistently highlighted how personal connections, whether with student staff, faculty, or upper-level students, were pivotal to their comfort and thriving in the machine shop.

At Institution A, Ryan, a second-year Mechanical Engineering student, described how seeking help from shop staff helped him feel comfortable using the shop in the long run:

> *"I think the first thing was like I had some little Raspberry Pi project I wanted to work on. And that ended up like getting me familiar with, or needing to learn how to solder, is how I learned like, how helpful and friendly the staff were there and then from there I kind of just, you know, wasn't afraid to ask for help anymore, and kind of just, things took off.*"

For Ryan, the technical necessity of learning to solder served as the catalyst for interacting with student staff. This positive interaction helped him realize that the environment was supportive rather than intimidating. This initial relational resource encouraged his continued use of the shop and lowered the barrier to asking for assistance later.

Elijah, a second-year Mechanical Engineering student at Institution A, narrated his connection with the machine shop through an upper-level student.

> *"An upperclassman student, [name], was sort of like a mentor to me academically, with like physics and stuff. And she recommended that, you know, I come into [name of the shop] and get trained as a freshman. So I got trained in all the different machines by then."*

At Institution A, students typically do not have formal contact with the machine shop through coursework until they declare their major in their second year. Therefore, it is rare for first-year students to use the space and learn to use the machines. Elijah's connection with an upper-level student bridged this institutional gap, helped him become aware of the space and provided him access to the learning resources offered there.

At Institution B, Rohan described how the communal nature of the shop facilitated his access to the expertise needed to complete his personal project:

> *"Yeah, I came in, and I was like, [faculty member 1], this is what I'm doing. And I knew [faculty member 1] already. And then [faculty member 1] was like, well, [faculty member 2] is really good at welding. And [name of faculty member 2] was like, Yeah, I've actually had experience with food-grade welding. And that's quite literally the conversation, because everyone was in one space and could overhear."*

When Rohan was conceptualizing an automated coffee pour-over machine, a casual conversation with one faculty member connected him to another who possessed the specific niche expertise (food-grade welding) required for the project. The physical proximity and personal connections of faculty in the shop turned a simple conversation into a valuable technical resource.

Personal connections in both institutions serve as vital relational resources. They function in multiple ways: acting as a "foot in the door" for early access, mitigating feelings of intimidation to foster a sense of belonging, and acting as a conduit for technical knowledge. These relationships are essential for encouraging students to participate fully in the machine shop community.

Discussion

These preliminary findings present examples of how ideational, material, and relational resources serve as identity resources to support students' participation in the machine shops. In this section, we discuss how identifying these identity resources informed us about how to redesign the machine shops to provide these identity resources.

Bite-sized training on machines

Our findings indicate that the one-off training structure at Institution A may create cognitive overload and anxiety for novice users by requiring them to absorb complex safety protocols and machining techniques in a single, high-stakes session. Instead, Institution B's model that provides a scaffolded approach and bite-sized training sessions better prepares students for using the machines confidently and independently later on. Furthermore, students may still need support after the initial training to get used to the machines, especially if there has been a gap since their training. Implementing facilitated practice sessions where students can revisit machines under low-stakes supervision to complete meaningful tasks can help them build skills. It lowers the psychological barrier, making it easier for students to move from novices to expert users of machines.

Institutional support for self-directed projects

Although personal projects serve as gateways for learning and exploration in machine shops, the cost of acquiring materials imposes a financial burden that exacerbates inequity. If there is no financial support, then learning through personal making is limited to those with the financial means to afford it. Institution B's "Passionate Pursuits" program highlights how institutional support can bridge this gap by providing essential material resources. Accordingly, redesign efforts should prioritize the creation of accessible funding mechanisms and infrastructure to support personal work. By institutionalizing financial and logistical support, universities can dismantle some socioeconomic barriers, ensuring that "learn by making" for personal interest and passion is an equitable opportunity for all students.

Hiring staff with diverse identities and interests

As illustrated by the experiences of Ryan, Elijah, and Rohan, personal connections are important relational resources for students to participate in the machine shop. However, relying solely on organic, serendipitous connections may not work for some students. To better provide relational resources for all students, machine shops should be intentional in their hiring practices and recruit staff who represent diverse identities and a broad spectrum of interests (e.g., crafting, food making, and traditional machining). Furthermore, redesign efforts should expand staff training beyond technicality to include inclusive pedagogy. This empowers staff to actively validate the participation of students who may perceive themselves as outsiders to the traditional engineering narratives. By diversifying both the personnel and the interests represented, machine shops can become an environment where diverse forms of practice-linked identities flourish.

Conclusion and Future Work

This work-in-progress study highlights that physical access to a machine shop does not guarantee meaningful participation. By viewing machine shops through the theoretical lens of identity resources, we revealed how factors such as training, funding mechanisms, and staffing can serve either as gateways or barriers to student engagement. Our preliminary comparison of two institutions illustrates that when these resources are intentionally curated (e.g., through scaffolded training sessions and funding like "Passionate Pursuits"), they validate students' identities and encourage deeper engagement.

These findings suggest that redesigning machine shops for approachability and equity requires moving beyond a focus on safety and equipment availability. Instead, institutions must intentionally cultivate ideational resources that validate diverse making interests, material resources that lower financial barriers, and relational resources that provide communal support networks.

In our future work, we plan to transcribe and code the full dataset of focus groups and interviews, and develop a comprehensive list of the identity resources afforded or not afforded in machine shops. To situate this work within the broader discourse on makerspace approachability, we will employ an intersectional lens to unpack how students' gendered and racialized identities influence their perceptions of certain resources. A certain type of resource could be more crucial for students with certain racial and gendered identities to develop practice-linked identities in a machine shop. For example, all three students who mentioned mentors as their relational resources were men. Although a full analysis of the dataset is required to understand these nuances, this observation provides a compelling thread for further investigation: whether gendered dynamics influence which resources students prioritize.

Ultimately, we intend to translate these insights into actionable strategies for institutional change and transform academic machine shops into environments where all students can develop the strong practice-linked identities that support their engineering learning.

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Appendix 1. Focus group questions

1. How would you say you engage in making and makerspaces in your life?
2. Tell me about the first time you learned about [name of machine shop].
3. Tell me about a time you've felt proud at [name of machine shop].
4. Tell me about a time you've felt frustrated at [name of machine shop].
5. Tell me about a time you needed help, and how you went about getting the help that you needed.
6. What skills have you acquired within [name of machine shop]? Could you pick one and describe how you acquired it?
7. Here is a list of resources that [name of machine shop] provides. Please mark your experience on the sheet. (Study participants are shown a list of resources, and asked if they have used, have heard of it, or have never heard of each resource.)
8. Is there a resource that you wish you had used? If so, what is stopping you from using it and how can [name of machine shop] better support you to use it?
9. How does [name of machine shop] support students coming in and making for personal projects or acquiring new skills?
10. What feelings does [name of machine shop] evoke for you?
11. If [name of machine shop] was a person with a personality, what would its personality be?
12. What does your ideal [name of machine shop] look like? When you walk in, who is there? What is going on?
13. What kind of presence do you think [name of machine shop] has been for your journey at [name of institution] to become an engineer? By “become an engineer,” we mean the process of figuring out what kind of engineer you want to become, or not become at all.

Appendix 2. Study participant demographics

Institution A	
Year of study	1st year: 4, 2nd year: 4, 3rd year: 9, 4th year: 5, 4+1 master's: 1
Major	ME: 20, HFE: 3
Gender	Female: 13, Male: 8, Other: 2
Staff or not	Not staff: 19, Staff: 4
Institution B	
Year of study	1st year: 4, 2nd year: 4, 3rd year: 2, 4th year: 1
Major	ME: 7, Electrical and Computer Engineering (ECE): 3, Robotics: 1
Gender	Female: 4, Male: 3, Other: 4
Staff or not	Not staff: 7, Staff: 4