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How SocioTechnical Learning Broadens Participation in STEM by Developing Self-Efficacy within Work-Based Experiences: Work in Progress

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Abstract

The nation's need for a diverse and competent Science, Technology, Engineering, and Mathematics (STEM) workforce contributing to economic growth, global competitiveness, and innovation is a primary driver for broadening participation in STEM. Yet, social justice and ethics policies dating as far back as the civil rights movement and earlier have not successfully diversified the current STEM workforce nor the STEM higher education system.

This paper looks across three qualitative studies during the work-based experiences (WBEs) of eleven undergraduate computer engineering and information technology systems students from groups traditionally underrepresented in STEM. In this paper, WBEs are defined as paid engagements for students as they work on solving real-world problems, while performing tasks and projects in partnership with an employer or community partner. Three types of WBEs are represented: internships (Study 1), apprenticeships (Study 2), and company employees (Study 3).

All three studies used the Socio-Technical Integration Research (STIR) methodology which has been established in 80 studies worldwide and over a dozen peer-reviewed publications. As a methodology STIR provides 1) a protocol for collaborative dialogs with an embedded humanist about upcoming decisions in the context of performing work-related activities and 2) a framework for analyzing the results of using the protocol to assess for reflexive and deliberate changes (modulation sequences). Additionally, we tested the efficacy of STIR to serve as a pedagogical intervention that supports SocioTechnical learning (STL). We define STL as 1) learning technical skills, 2) learning to reason about the normative societal dimensions of technology decisions, and 3) applying social and technical learning together in the context of work-based experiences.

Using a combination of deductive coding and temporal analysis, several empirical findings emerged, including: During each WBE, STL was found to occur, regular STIR dialogs supported STL, and STL strengthened self-efficacy. These and other qualities of STL were found to help advance Broadening Participation in STEM as it is theorized in the literature.

1. Introduction[1]

Broadening Participation in STEM (BPiS) is a major initiative funded by the National Science Foundation (NSF) in a range of micro-, meso-, macro-, and exo-level programs that span formal and informal education settings for pre-kindergarten thru secondary, undergraduate, graduate, and postgraduate levels, on to transitioning into the STEM workforce as researchers, scientists, engineers, or other STEM professional careers. According to the NSF, "A diverse and capable workforce is vital to maintaining the nation's standard of excellence in STEM" [1]. At the micro-level, for NSF, BPiS means increasing STEM opportunities for individuals from underrepresented groups, regardless of their "racial, ethnic, geographic and socioeconomic backgrounds, sexual orientations, gender identities, and to persons with disabilities" [1]. Data from 2021 indicate that two-thirds of the STEM workforce is made up of men, and collectively, underrepresented minorities (URMs) make up 24% of the STEM workforce [2]. These groups include Hispanic, Black, Native American, or Alaska natives. To address these gaps, the National Academies of Sciences, Engineering, and Medicine (NASEM) held a virtual symposium where participants imagined the future of STEM undergraduate education in 2040 as more accessible, inclusive, and equitable, highlighting the important role of community colleges in making this happen [3]. An important need emerged, "to put less value on degree and more on competencies, experiences, and skills." This need was supported by employers' preference for "critical thinkers who can apply learned information and skills to become specialists with on-the-job training" [3].

In *Broadening Participation in STEM: Effective Methods, Practices, and Programs*, Wilson-Kennedy, et al., (2019) compiled fourteen case study programs and their high impact practices (HIPs) that improved inclusion and success of underrepresented persons in STEM [4]. Importantly, some of the HIPS are related to *Experiential Learning,* defined by Dewey (1937) as a cyclical learning model in the education process with four components: concrete experience, *reflection*, abstraction, and application [5].

Experiential learning refers to the transformation of experiences into applied knowledge [6] with a deliberate importance placed on the reflexive nature of learning [7]. Kolb's experiential learning theory is a noted example of a commonly cited learning theory presented in the literature that maintains humanistic roots [8]. Experiential learning theory not only includes the cognitive aspects of learning, but also addresses one's subjective experiences [9], defining learning as "the process whereby knowledge is created through the transformation of experience" (Kolb, 1984, p. 41). This theory suggests that following an experience, the individual reflects on the experience, and it is through this reflexive process that one transforms their learning into knowledge, which in turn influences future actions taken by the individual [7].

The chapter 7 study in Wilson-Kennedy, et al., (2019) provides ten high impact practices (HIPs) of which two are *work-based forms of experiential learning* [11]. That is, they are situated in real-world problems, tasks, and projects in partnership with an employer or community partner. The two HIP case studies associated with work-based learning are internships and community service/community-based learning. Two additional HIPs are worth noting, but do not by default offer work-based experiential learning scenarios. They are capstone projects and collaborative

[1] This paper is a high level discussion of a portion of the findings from the first author's dissertation which is available upon request.

projects that could be contextualized to work-based experiential learning. This is also discussed by Kuh, who, in addition to internships, presents community service and capstone projects as HIPs that enhance students' employability [12].

Another relevant study explored the development of T-shaped or holistic problem solving skills and their application to solve real world problems by undergraduates in technology degree programs. This study found that holistic problem solving skills were very important for getting a first job and technical depth was not as important [13].

The contributions of work-based experiential learning to STEM student retention are highlighted by Raelin as related to work, career, and academic *self-efficacy* [14]. According to Bandura, self-efficacy is an individual's belief in their capacity and skills to achieve specific goals [15], [16], [17], [18]. Academic self-efficacy pertains to a students' beliefs in their successful performance in STEM courses, career self-efficacy pertains to students' beliefs about success in their chosen STEM career and decisions about choosing or changing their careers of choice [19], [20], [21], [22]; and work self-efficacy has to do with students' beliefs about their ability to succeed in the workplace [14]. Multiple studies have shown improvements to work and career self-efficacy for undergraduate engineering students while engaged in cooperative work study placements [14], [23], [24], [25]. Of these studies, two tied the self-efficacy gains to increased student retention [14], [25] which is a major enabler for broadening participation in STEM.

The work self-efficacy inventory is organized by seven subscales: sensitivity, communications, problem-solving, teamwork, pressure, politics, and learning [25]. The subscales map to instrumental social skills viewed as essential by industry employers and often insufficiently developed in students newly entering the STEM workforce [13], [26], [27], [28], [29].

Six subscales of career self-efficacy include occupational information, goal selection, planning for the future, goal selection, self appraisal and social affirmation. The first five subscales were defined by [22] in their CDMSE model. Arlinkasari et al. 2015 and 2016 used the CDMSE model in their study and added the Social Affirmation subscale [19], [20], which adds cultural and familial considerations.

Several experiential learning theories are applicable to work-based experiential learning in STEM, a specialized form of experiential learning within real-world projects where students apply STEM skills and knowledge. However, no common theoretical conceptualization of work-based experiential learning exists [30], [31]. That said, most experiential learning theories support the need for *reflection*, conceptualisation, and evolution of applicable theories [30]. Two theoretical studies are worth noting as related to work-based experiential learning, and are described next.

The findings/work of Schön and Raelin are important because they provide promising ways in which work-based experiential learning could be formalized through reflection that inform the proposed methodology. Schön (1988) posits that practitioners create theory as they reflect on real world problems and challenges arising in their practice, suggesting that grounded theory could be a viable approach, and also perhaps a common theoretical conceptualization is not realistic. He also argues that reciprocal reflection-in-action in dialogs with a coach during a *reflective practicum* (a real-world project during which the student applies their academic knowledge) contribute to effective learning [32]. Additionally, Schön also claims that reflection-in-action is also not a single time-boxed occurrence; it can occur multiple times, at different intervals and different durations [32].

Raelin introduced a model of work-based learning at the individual level that portrays learning and knowledge in a four quadrant layout [33]. Note that reflection and practical experience are key components of the model, as well as the combination of theory and practice. Raelin also builds on the idea that reflection is a *temporal phenomenon* that occurs over a spectrum of five-levels of reflective practice [33].

More recently, Hansen describes several models of reflection used in empirical experiential learning contexts related to career-based learning [27]. And, Irvin introduced *guided reflection* into on-campus employment of students to elevate and strengthen career-based learning as a HIP [34].

Hearkening back to HIPs and learning theory in the literature, there may be different types of experiential learning that can become more qualified as HIPs and contribute new knowledge, for instance when reflection is explicitly included and / or guided during work-based learning experiences. Another knowledge contribution, especially to the goal of broadening participation in STEM is understanding ways in which different forms of guided reflection, e.g. pedagogical and dialogical, potentially contribute to work and career self-efficacy, to positively impact retention and ongoing success of URM students in STEM.

The prior concepts and foundational background rationalize the importance of this research.

2. Goals and Objectives

The proposed research seeks to develop technology and engineering students by deepening their reflexiveness about their life worlds and career trajectories, increasing their future-making agency and sense of civic responsibility. By engaging with undergraduate STEM students using Socio-Technical Integration Research (STIR), this research expands current work-based experiential learning (WBEL) practices beyond a default agenda to develop a technically skilled workforce. Stronger ties to human and societal dimensions in WBEL projects have the potential to increase engagement of underrepresented minorities in STEM.

In undergraduate STEM education there is currently a gap, especially for students engaged in work-based experiential learning projects, a high impact practice that improves retention of underrepresented minorities and their preparation to enter the workforce: **Students do not apply social and technical learning together in the context of making decisions related to the technologies used in projects and how those decisions impact human and social dimensions.** This is an important gap–both in pedagogical approaches and scholarly literature–because enacting decisions moves beyond demonstrating *awareness* of normative social dimensions to enacting *deliberate adjustments* to material practices, behaviors, relationships with others, and/or long-term strategies that comprehend normative social dimensions as a result of learned insights and through critical reflection. Bringing social and technical learning together in the context of work-based experiential learning in the fields of information technology, computer engineering, and information systems appears to have the potential to synergistically: 1) Broaden participation in STEM through increased retention and workforce preparedness, and also 2) Highlight how cultural values and assets of underrepresented groups can enhance decision making in STEM projects and product development which contributes to innovation and other economic drivers.

The broader public impacts are two-fold. First, by enabling students to recognize themselves as agents for positive social change, the proposed research has the potential to broaden participation in STEM by increasing engagement, retention, and graduation of underrepresented minorities. Second, in building SocioTechnical Learning capacity, the research will also contribute to new approaches for community centered solutions that leverage cultural assets of underrepresented students and consider alternative knowledges in collaborative technology design, development, and implementation. As students graduate and enter the workforce, they carry with them the capacity to respond to human and societal dimensions of technology in daily practices.

3. Conceptual Framework

The literature characterizes multiple separate flavors of social learning and techno-centric learning in the context of undergraduate STEM. Emerging studies in engineering education enumerate socio-technical issues and considerations, but few if none of these studies have named or set clear conceptual boundaries for SocioTechnical Learning. Moreover, there is very little if any explicit treatment of the integration of normative social dimensions into technical decision making in the context of work-based experiential learning.

Because of the emphasis on reflection and self-efficacy in the work-based experiential learning literature, the proposed conceptual framework builds on the theoretical work of Schön, Raelin, Hansen, Irvin and Betz. The theoretical underpinnings will be informed by the methodological perspective of Socio-Technical Integration Research (STIR) [35] [36]. STIR includes a collaborative decision protocol and methodology [36], [37] that has been applied in dozens of different STEM settings worldwide. Because of its iterative process and flexibility to incrementally adjust the protocol, STIR makes sense as the primary method for the context under study and participants' styles of interaction. Since STIR is applied within the environment where participants work as they engage in daily activities, it is minimal overhead. As a mode of teaching and learning with scientists and engineers [38], STIR can also be considered as intrinsically pedagogical: collaborative STIR dialogs [37] are designed to productively disrupt practices and generate changes that are consistently documented in an ongoing process of description through knowledge produced in the discussion. The changes are referred to as modulations of which there are three types: de facto, reflexive, and deliberate. Because of the collaborative and reflective nature of STIR dialogs, it can be viewed as an exchange between the social scientist who is also a critical pedagogue and the technical participant who is learning to become critically aware of their technical decisions and the impact to others in the world. Thus STIR is a dialogical and pedagogical approach to guided reflection.

While the research described in this paper is primarily dialogical, Conley's work in Anticipatory Ethical Research [39] explores a pedagogical approach that also draws upon a STIR foundation. In Creative Anticipatory Ethical Reasoning Process (CAER) Workshops [40], students applied anticipatory ethical reasoning using two of the eight key ethical questions, which are organized by topics such as empathy, fairness, responsibility, character, outcomes, and others [41]. The

CAER approach differs from the way in which engineering students traditionally engage with traditional professional ethics based on industry standards, honest reporting of data, cost benefit tradeoffs, and analysis of case studies when standards or professional codes of practice were violated [39].

From the above-described body of literature about work-based forms of experiential learning, self-efficacy, STIR, and anticipatory ethical reasoning, a new conceptual framework for SocioTechnical Learning (STL) is proposed which is later supported by empirical findings in Section 5 and theorized in Section 6. STL is defined as 1) learning technical skills, 2) learning to reason about the normative societal dimensions of technology decisions, and 3) applying social and technical learning together in the context of their work-based experiences.

4. Experimental Design and Methodology

As seen in Table 1, the research design intentionally included cross site similarities for: college level (undergraduate), Demographics, WBE Application Domain (Computer Engineering, Information Technology, Information and Communications Technology), Type of Site (2-year HSI and/or Employer), and WBE Customer (Community Partner within the Application Domain). Two empirical dimensions of comparison that seem to matter in our findings emerged during the research: **Organizational culture** and **level of autonomy**. These two are somewhat interrelated in that the embedded social scientist (ESS) observed that the organizational culture influenced the level of autonomy expected and instilled in the student workers, which in turn positively or negatively influenced self-confidence in their work skills or career choices. The **demographics** of participants also seemed to matter. Section 5, will expand upon how each of these dimensions mattered, as related to SocioTechnical Learning and self-efficacy.

Table 1: Experimental design, participants, and dimensions of comparison across research sites

Research Study, Year, Site	# of STIR participants, demographic: pseudonym	Role of undergrad participants in WBE	WBE Application Domain	WBE Customer	WBE Setting	Org. Culture	Participant Level of Autonomy
Study 1 2021 2-year HSI 1	Three (3) 2 African: A, C 1 Hispanic: B 1 woman: C	Paid Intern	Digital Divide (DD) in Education	Title I HS District IT deploying DD	Hybrid: on-campus and via recordings	Inclusive, nurturing, serving.	LOW
Study 2 2022 2-year HSI 2	Two (2) 2 White: D, E 1 woman: E	Paid Apprentice	IT Support Tech	Employers and their business or consumer customers	Started: on-campus Moved to: Employer	Inclusive, enrolling. Employer dependent.	MEDIUM
Study 3 2023 Small Tech Company X	Three (3) 2 Hispanic: F, G 1 Middle Eastern: H 1 woman: F	Paid Employee	IT Support K12 STEM Program Delivery	Employer's customers Students at Title I K12 Districts	Employer *and/or* At K12 schools	Inclusive, equitable, engaging, expectations, serving.	HIGH

Note: In the above table, Title I refers to Schools with a free and reduced lunch % greater than 35%. Title I funding is allocated to more than 90% of the nation's schools to offset the effects of poverty.

Figure 2 provides an overview of the four stages of the experimental process: Recruitment, Qualitative Data Collection, Incremental Analysis, and Post Analysis. Eleven participants across three research sites were recruited and consented prior to qualitative data collection. Two semi-structured interviews of 24 identical questions at the beginning and end of each study, were conducted to identify differences between control and STIR participants and changes in individuals' conceptions of socio-technical integration after participating in the study. At the end of each study, the ESS conducted semi-structured interviews to assess outcomes from the WBE related to work and career self-efficacy and persistence in their field of study. Full participants engaged in regular individual STIR dialogs with the ESS. Other data streams included group observations and artifacts created by the participants and instructors.

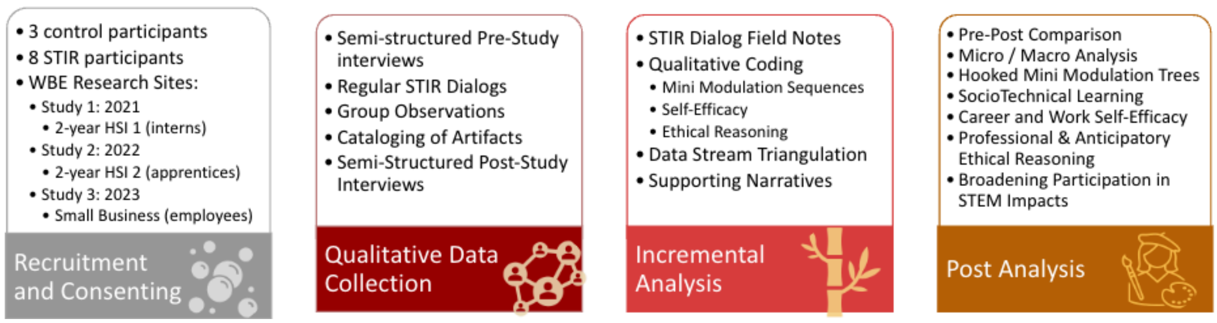

Figure 2: Experimental process across the three research studies

Methodologically, a STIR dialog involves an embedded social scientist (ESS) and a participant (STIRee) who engage in a collaborative semi-structured discussion. The protocol represented as a four quadrant diagram (Focus upper left; Considerations, upper right; Alternatives, lower right; and Outcomes, lower left) guides the discussion, with prompts from the ESS as needed. Initially, the ESS asks for an upcoming decision or problem to focus the STIR dialog. When crystallized by the STIRee, the ESS writes it into the Focus quadrant. Ideally the dialog progresses clockwise around the four quadrants, but it depends on how the discussion proceeds naturally. The ESS may need to ask about Considerations at a later point if the STIRee goes directly to Alternatives, but they will capture Alternatives as they are discussed even if they are intermingled with Considerations. At the close of the dialog, the ESS summarizes key points highlighting any reflexive or deliberate modulations [38].

Incremental analysis of the STIR dialogs began as early as week one of each study, via analysis of field notes and thematic deductive coding of identified modulations, if they represented technical learning or also considered human and social dimensions, and whether they contained ethics-related, work self-efficacy, or career-self efficacy themes. After two or three STIR dialogs, analysis and identification of modulation sequences began. Modulation sequences show changes in participants' reflexive thinking and deliberate actions over time – in this paper, the students' capacity for SocioTechnical learning that considers impacts of their technical decisions to humans and society. In their WBEs students also discussed work and career-related decisions; we developed codes for work and career self-efficacy based on corresponding substrates found in the literature and overlaid the modulation sequences with these codes to capture contextualized support provided by STIR. The sequences were augmented with supporting narratives and triangulation of data from participant-observation, group observations, and inspection of documents and other artifacts produced by the participants as part of their work-based experiential learning.

As in a typical STIR study, the modulation sequences, narratives, and stories continued to evolve during ongoing STIR dialogs. Through temporal analysis, theoretical patterns for SocioTechnical Learning, evolving ethical reasoning, and self-efficacy emerged from the empirical data. The qualitative data collection, deductive coding, and temporal analysis were intertwined, which increased the speed of the overall analysis, so that analysis after completing data collection ("post analysis") focused on comparison of the pre-post interview responses, their mapping, if any, to themes identified in the modulation sequences, and the micro and macro analysis across the three studies.

5. Overview of Empirical Research Findings

This section discusses select findings from the three studies. SocioTechnical Learning was enhanced throughout STIR dialogs where a student worker and the STIR researcher explored together learning the technology content while also considering the impacts of technology decisions to humans and society. The three studies each yielded multiple examples of SocioTechnical Learning. The following subsections present one example from each study followed by a discussion of how work and career self-efficacy developed across the three studies.

5.1 Study 1: Improving a technical solution using Spanish Translation as a Cultural Asset

Study 1 took place at local 2-year HSI 1, where paid student interns engaged in lab-based, hands-on projects to test digital divide equipment configurations. After introductory training, each intern was assigned a piece of equipment which was a solution component within the overall system to be deployed at a local Title I high school district and its feeder schools.

In Study 1, an example of SocioTechnical Learning by participant B, a Hispanic male, stands out: Spanish translation of instructions to setup equipment. This example occurred during the hands-on project to test "WiFi" devices and create video and text instructions for their installation and use by high school students in their homes.

In the third STIR dialog with B, a strong technology focus dominated (how to assemble the digital divide equipment) because creating video and textual instructions from hands-on experience with the equipment was the primary assignment at this phase of the internship. The STIR dialog initially focused on decisions, considerations, alternatives, and anticipated outcomes for creating these instructions. In the modulation sequence, B expanded upon his de facto attitudes about communicating and listening instead of making assumptions about what solutions high school students need. B reflected that he needed to further contextualize the instructions to student perspectives. Then he ideated ways to bring in those perspectives and test them with kids in the target age groups. During the discussion of outcomes and who cares about the outcomes but relatable to considerations and alternatives mentioned earlier in the same STIR dialog, B recognized the role / importance of adults in understanding the instructions too, based on his personal experience, in which his mother who spoke English as a second language, helped her seven children with their homework assignments. He remarked, "Parents…might have to help with or even do the setup." However, "Many [parents] do not understand English well in my experience.” Therefore, “A Spanish translation would…be very helpful. I highly recommend it.” B then committed to a new task: “I'd be willing to help with a Spanish translation.”

Later, at the group report to the high school district implementation team, the interns recommended language translation. In the ensuing discussion, the team learned that the four interns collectively speak seven languages which mapped to demographics of the high school students receiving digital divide equipment. The implementation team agreed that language translation would be helpful.

During Study 1, instructor-led learning of an emerging technology to address the digital divide in education fueled students’ agency enabling them to apply their technical learning in lab-based, hands-on projects. The instructor-led learning was helpful to the students for whom digital divide technology was a new and unfamiliar technology. The student interns were excited to learn the emerging technology and contribute to its application in their local community.

Regular STIR dialogs alongside the classroom technical learning and hands-on project-based experiential learning elicited examples of SocioTechnical Learning that spanned human, social, and technical dimensions in the context of their digital divide project. Each learner started from a different beginning point and each took a progressive "step" forward[2]. As their confidence in knowing the technology grew, they began to integrate their cultural assets into their projects, which increased the likelihood of smoother uptake by high school students with similar cultural backgrounds. This showed sensitivity to others in the community, a form of ethical reasoning.

This and other examples from Study 1 show that STL occurred, and that it was supported by regular STIR dialogs.

5.2 Study 2: Improving work and career self-efficacy through reflective problem-solving

Study 2 took place at local 2-year HSI 2, within a reskilling program sponsored by the Workforce Innovation and Opportunity Act (WIOA). The IT Tech Support Apprenticeship program first developed participants’ Comptia A+ IT knowledge and skills, then required passing two industry recognized exams, prior to placement in a nine month apprenticeship with a local employer.

In Study 2, participant E, a white female, stated that she “enrolled in the IT support specialist apprenticeship program to improve her career prospects and make enough money to support herself in a better lifestyle.” With extensive experience in the service industry as a hairstylist, she planned to develop technical skills to help “people who are not tech savvy in a more personable non-geeky manner.” Although an early benefit of our STIR dialogs was in getting E through the technical learning so she could leverage her social strengths in a more lucrative career trajectory, the subsequent work and career self-efficacy outcomes are more relevant to this paper. In particular, the following SocioTechnical Learning example shows how E <u>improved work and career self-efficacy through reflective problem-solving</u>.

Early in her apprenticeship, E’s primary concern was establishing a routine. When asked about alternative ways to establish her routine, E responded with specific examples of customer

[2] Additional details and other examples from Study 1 are available [42], [43].

interactions, indicating she viewed customer interactions as an important part of her routine. Her response showed deepening of her de facto values and goals for providing good customer service to the context of her apprenticeship and specific types of services she needed to provide on a daily basis.

As time passed, E hungered for "feedback that she was doing really well in her job from her employer and the more experienced technicians" she worked with. In particular, she reflected, "an area of growth for me would be deciding whether to fix an issue or escalate it to a more experienced Technician." This was an important self-assessment and decision that E would face several times a day throughout her 8-month apprenticeship. Over several STIR dialogs, she articulated a foundational decision process important to her continued SocioTechnical Learning. E realized she needed to maintain good customer service, uphold privacy and security, and continuously: grow her knowledge about how to fix various issues based on learned experiences; reason about how to fix newly encountered issues using troubleshooting scripts; or decide when to hand-off to someone else. E's response showed that she was settling into the apprenticeship and recognized a foundational on-the-job routine for resolving her customers' issues that could evolve over time as she increased her technical knowledge. E now realized that establishing her routine was not a one time, static event. In a subsequent STIR dialog, when asked about her progress in deciding whether to fix or escalate, E confidently reported:

> I can fix computers by myself now, I don't always need assistance on the technical side ... I've been cloning [failed] hard drives over to new computers so people don't lose all of their data. I can remove malware that people clicked on because they didn't know it was a scam...

In the above excerpt, E applied insights from her reflexive realization for her needed growth to make decisions about repairing specific issues and then performing the needed repairs. In doing so, she increased her skills and knowledge of how to fix multiple common issues. Her understanding of her routine also evolved to include customer relations and service provided to customers in addition to earlier and more basic ideas of getting to work on time.

In the multiple STIR dialogs after her apprenticeship placement, together E and the ESS reasoned through her getting spun up and into the job routine, building confidence to resolve customer computer issues on her own, and thinking about career growth opportunities beyond the entry-level apprenticeship position.

E's placement was a good fit for her customer service strengths and increased her confidence in hands-on computer hardware fixes and the related customer interactions to rationalize why fixes were needed. E's approach to her professional routine became more sophisticated in incremental stages and evolved over time in conjunction with the STIR dialogs. In addition to knowledge and skills learned during the apprenticeship, E also built her confidence in a male-dominated field that she was reskilling to enter.

This and other examples from Study 2 show that STL occurred, that it was supported by regular STIR dialogs, and also that it enhanced self-efficacy.

5.3 Study 3: Improving learning for a broad audience despite limited time and resources

In Study 3, the three undergraduate participants F, G, and H were employees of Small Tech Company X. As employees of X, they provided non-curricular or elective STEM programs at local Title I schools. All participants had responsibility for managing classroom dynamics in addition to teaching STEM program curricula such as 3D printing, rocket science, robotics, microbit circuits, and building computers.

Crazy Computer Build (CCB) was offered as a non-curricular or elective program for middle school students that participants F and H implemented. CCB is especially interesting because of its BPiS fan out. Beyond the STIR participants in Study 3, CCB enabled six high school interns employed by X to earn career technical education (CTE) credits because they refurbished the practice computers and take-home computers for 102 middle school students in Title I schools. Participant F, a female Hispanic deferred action for childhood arrivals (DACA) student and X employee, led orchestration for CCB and H was a CCB instructor.

As the reader may imagine, pulling off a successful CCB offers unfolding opportunities and challenges during orchestration, computer refurbishing, and middle school student instruction. In at least five STIR dialogs and follow-on sessions F and the ESS discussed how to coordinate the computer take-home event with the school administrators to decide the date, and then ensure the computers and the CCB students were ready. One key challenge was communicating the take-home event to students' parents who would need to attend the event and pick up their child to transport the computer, mouse, keyboard, cables, and monitor home. After our discussion of considerations and possible alternatives, F decided to pursue the alternative to confirm parents' availability for computer pick-up using both Spanish and English fliers sent home for parent signature.

Another key challenge was refurbishing donated computers, which F framed as "an opportunity for six high school (HS) student interns employed by X (1 Asian, 3 Hispanic, 2 white; 2 female, 4 male) to complete intern hours for their CTE class." Together, F and the ESS reasoned through "when and where" to train the six HS interns to refurbish computers and also successfully refurbish 102 computers. Our STIR dialogs helped F to layout the space of possibilities and achieve clarity in her decision making to optimize her resources. While completing their CTE intern hours, the HS interns learned: "hands-on refurbishment skills, hardware skills, programming, erasing the computer, booting up Linux, and matching monitors. They got really quick at the end, they loved it. Two of them are interested in going to school for computer engineering."

As mentioned previously, H's role was to instruct CCB, in addition to other STEM programs. The ESS learned of the decision to delay H's CCB computer pick-up event to the Spring from both F and H. The reasons centered on what was best for the middle school students. According to F, G was teaching the thirty lesson CCB, and was only on lesson five by the last day of classes in December, whereas the other three instructors taught the shorter CCB and were finished by the last day. F advocated to the leadership team at X, "It's not fair for the kids. It's a lot of information, and it's not fair for H that he has to rush through the lessons. It's not fair for them, so let's just push it back to next quarter." The leadership team and F decided to focus on the schools where the kids had already finished shorter CCB and also gauged their decision on the number of take-home computers that were ready. Meanwhile H, the instructor for the longer CCB, claimed, " I chose to do the long CCB curriculum (30 lessons) for three reasons: 1) so the kids can take their time; it's better for them; they learn more; 2) I enjoy teaching it; and 3) enough refurbished computers were not ready yet."

In our final STIR session, F reflected:

> The events where we gave out the refurbished take-home computers went really great. Logistically, there are a couple of improvements we could have done, like bringing in more bi-lingual instructors, especially for the larger groups. Altogether 102 refurbished take-home computers were given to students at three Title I schools in grades 6, 7, 8. About 80% of the students were Hispanic. A small percentage were African Americans, and less than 5% White. The ratio of boys to girls was about 70% males, 30% females.

The CCB example clearly illustrates broadening participation impacts because it provided take-home computers to URM middle school students living in impoverished neighborhoods. It also enriched recipients' knowledge and skills in working with computers and provided a tool for potentially improving their future prospects. During CCB, F and H's SocioTechnical Learning exhibited the following work self-efficacy subscales: teamwork, performing under pressure, and navigating organizational politics. For instance, in this example, F orchestrated a win/win scenario with the X leadership team and H because she wanted to "make it more fair to both H and his students, so they didn't have to rush through CCB" in just two weeks. She also felt empowered to influence things in this manner because of the underlying company culture of support where "each employee plays a direct and integrated role in running the business." No one placed the blame on another person, instead they worked together to develop a better solution for all parties involved: HS interns who earned CTE credits, instructors, middle school students, and their families.

This and other examples from Study 3 show that STL occurred, that it was supported by regular STIR dialogs, and that it enhanced self-efficacy.

5.4 Development of Work and Career Self-Efficacy

In all three studies, STIR helped develop work and career self-efficacy by providing contextualized support when reasoning through considerations and alternatives pertaining to work and career-related decisions, then discussing who cares about the outcomes and why. These collaborative discussions with an empathetic, neutral third party helped participants' reason through career choices, planning, self appraisal, or possible changes.

Overlaying work and career self-efficacy codes upon STIR modulation sequences helped to capture the temporal progression of confidence building over time. When we discussed how to learn or practice a particular work-related skill or make a career decision they were uncertain about, sometimes it bolstered a student's confidence to move forward and implement what was previously discussed. This was discovered in regular followup discussions that included rich dialogs and reflection about what happened during implementation. In some cases, these dialogs revealed that *the act of doing* led to increased confidence that reinforced SocioTechnical Learning.

This *act of doing* effect was observed in several instances. For example, during Study 2, E's SocioTechnical Learning supported by STIR dialogues benefited her career self-efficacy and even potentially helped her remain in the program despite the potential risk at one point of her dropping out. She had initially been concerned about the pay rate and growth opportunities available to her in the new STEM career she was about to embark on, but over time as she continued to apply herself in the program, she realized that she had a company and team that would support her growth, and she remained in the program.

In the post-study interviews, self-reported responses to work and career self-efficacy prompts supported observations captured in the modulation sequence overlays for work and career self-efficacy. For example, E reported "Everything that I've been doing here and how this job is run -- It's definitely helped solidify the fact that I made the right [career] decision."

6. Conclusion

Using a combination of deductive coding and temporal analysis, four main empirical findings emerged: **During a WBE, 1) STL as defined occurred; 2) STIR supports STL; 3) STL strengthens self-efficacy; 4) These and other qualities of STL help advance BPiS.**

Specifically, in all three studies, STIR was shown to provide contextualized support for individuals from groups traditionally underrepresented in STEM during work-based experiences to enhance their SocioTechnical Learning. The contextualized support was in the form of guided dialogical interactions that linked to critical reflections and deliberate changes in students' material practices and behaviors, also referred to as modulations. SocioTechnical Learning was enhanced throughout STIR dialogs where the student and the STIR researcher explored together learning the technology content while also discussing the impacts of technology decisions to humans and society. Using STIR also helped to elicit and capture the temporal progression of career and work self-efficacy during the WBE when discussing <u>how</u> to learn or practice a particular skill or what was involved in making a decision. Regularly offering this type of elicitation provided encouragement and bolstered students' confidence to move forward and try what the students had previously discussed. In some cases, STIR dialogs revealed that the *act of doing* led to increased confidence and further reinforced SocioTechnical Learning. In conclusion, the combination of work-based experiential learning and STIR builds work and career self-efficacy to increase persistence, both of which are theorized in the literature to strengthen Broadening Participation in STEM.

These findings and their interrelationships are depicted in Figure 1.

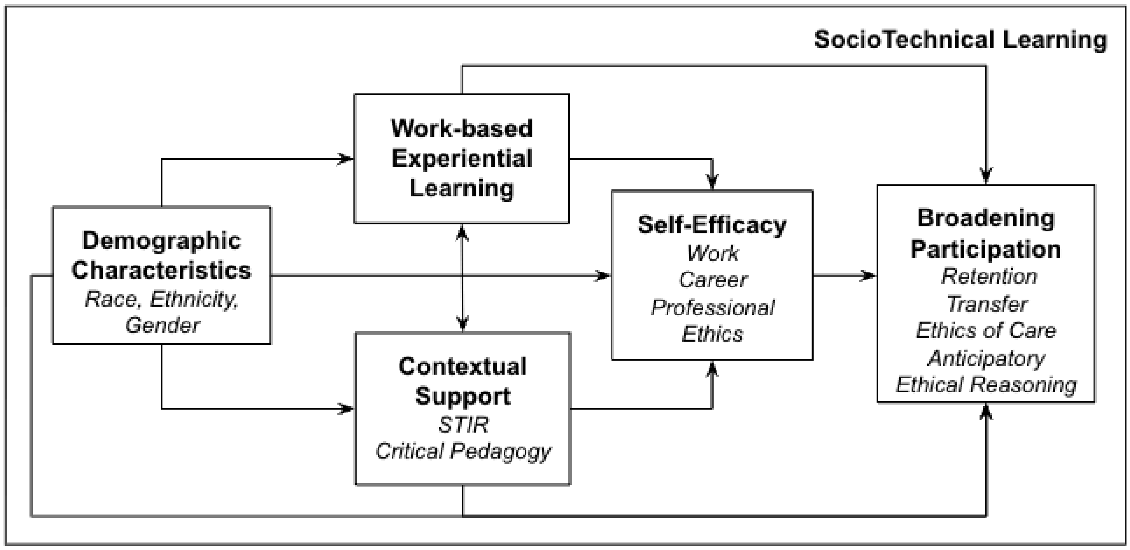

Figure 1: STL Combines Key Concepts Adapted from Schön, Raelin, Hansen, Irvin, Betz, Fisher, Conley.

7. Implications for Future Research

Three directions for future research recommended from this study include scaling the approach, implications for engineering educators, and general learning conditions and scenarios for use in work-based experiences.

To scale beyond individual interactions with the eleven undergraduates, approaches that engage larger groups such as those used in CAER[44][40] could be used to train faculty to facilitate group STIR sessions with their students to explore larger societal implications using anticipatory ethical reasoning. Another case study tested an adaptation of STIR with students of natural science at the University of Szeged, Hungary. The focus of the study was to facilitate responsible research and innovation awareness in Generation Z students. Instead of one-on-one STIR dialogs with experts about their daily activities, the researchers conducted weekly STIR focus group discussions with seven undergraduate students about 'what-if' scenarios based on historical examples [45]. Each week, one student delivered a short presentation about a historical example and its associated responsible research and innovation (RRI) issues, after which the focus group engaged in a facilitated STIR dialog.

A good first step if an institution does not offer internships, is to bring in speakers from local companies to the classroom. These types of engagements could lead to mentoring relationships, targeted workshops, or future internship opportunities. Don't ignore personal networks as an initial source. Students could also be a resource for maximizing the potential of these sessions. For example, the group could engage in a planning activity for bringing in an industry speaker by using the STIR protocol to focus and structure the discussion, reason through considerations and alternatives, and desired outcomes.

Engineering educators should consider including career workshop modules as part of internships and project-based learning, such as capstone courses. Incorporating STIR dialogs as a wraparound in group discussions or advising sessions with career services staff could provide contextualized support to explore considerations, alternatives and desired outcomes of career related decisions. Possible scenarios include preparing for an upcoming interview or hypothesizing a change in career path or major. After the initial planning and preparation, Mock Interviews within the group and / or with employee volunteers provide an incremental way to build confidence.

As experienced in the STIR sessions, WBEs might also benefit from incorporating practice of general learning conditions such as empathetic listening, reflection, and accountability. WBEs are a good testbed for learning and practicing employability skills such as team building, communication, and problem-solving. Encouraging engineering students to anticipate what might happen from their technical decisions through future thinking, storytelling, and case study discussions are all approaches that deepen reflexiveness about their life worlds and career trajectories, to increase their future-making agency and sense of civic responsibility. These types of discussions complement other well known WBEL approaches and activities.

Acronyms

Acronym	Definition	Acronym	Definition
AS	Associate in Science	HIP	High Impact Practice
BPiS	Broadening Participation in STEM	HSI	Hispanic Serving Institution
BS	Bachelors in Science	IT	Information Technology
CAER	Creative Anticipatory Ethical Reasoning	K12	Kindergarten through 12th grade
CCB	Crazy Computer Build	NSF	National Science Foundation
CC	Community College	NASEM	National Academies of Sciences, Engineering, and Medicine
Cert	Certificate	STEM	Science, Technology, Engineering and Mathematics
CIS	Computer Information Systems	STIR	Socio-Technical Integration Research
CIT	Computing and Information Technology	STL	SocioTechnical Learning
CTE	Career and Technical Education	URM	Underrepresented Minority
DD	Digital Divide	WBE	Work-based Experience
ESS	Embedded Social Scientist	WBEL	Work-based Experiential Learning

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