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Broadening Participation in STEM: How Socio-Technical Dialogs Improve Learning and Persistence in Engineering Undergraduates

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Abstract

Despite a long-standing history of policies for equity, inclusion, and capacity-building in science and technology, the US educational system has yet to sufficiently broaden participation in STEM (BPiS) to meet growing demand for advanced technology skills. This qualitative case study assesses to what extent regular dialogs with three underrepresented engineering students following the Socio-Technical Integration Research (STIR) method improved students' learning and persistence, contributing to US BPiS goals and aspirations. In this study, STIR is used to address the competency gap where little or no consideration of societal impacts occur during technical learning and decisions by engineering students. The setting for technical learning and decision-making takes place in an internship, which is a high impact practice for experiential learning in engineering education.

Traditionally internships focus primarily on technological projects. However in this study, over the course of multiple STIR dialogs with a social scientist, participating computing and information systems (CIS) students expanded upon their de facto practices through increased awareness of societal impacts during technology centric projects. In some instances, this awareness led to altering decisions and practices as they incorporated societal values and impacts in their technology projects. This phenomenon concurs with findings from other STIR studies.

During the internship, each individual discussed their own challenge(s) in meeting certain internship requirements. In a STIR dialog focussed on the challenge, each formulated strategies to address the challenge, and later acted on the strategy – contributing to continued persistence and completion of the internship. After the internship, additional persistence paths were discovered as internship completers earned CIS degrees, pursued higher degrees, and/or transitioned to a job in their field of study.

After learning the technology, STIR dialogs increased consideration of societal impacts in making technical decisions which supported equitable service to a vulnerable community, potentially enabling broader impacts beyond the engineers-in-the-making in this study. A new term, SocioTechnical learning, was coined to characterize the empirically observed steps in this case study: learning technical skills, learning to reason about societal contexts of technology decisions, and applying both social and technical learning in decision-making during their CIS projects.

The overall finding from this case study is that **STIR amplifies the potential for work-based experiences such as internships to broaden participation in STEM.**

Three ways that STIR supported the overall finding include: 1) Changes to participant awareness, behaviors and practices that considered societal impacts occurred over time as demonstrated in other STIR studies; 2) strengthened persistence during and after the internship; and 3) SocioTechnical Learning, an empirically observed phenomenon.

Introduction

US federal efforts to cultivate a diverse and competent STEM workforce span more than a century. Early on, the 1890 Morrill Act established historically black colleges and universities as land-grant institutions. More recent programs include the Civil Rights Act of 1964, Title III (1966) of the Higher Education Act (1965), the National Science Foundation (NSF)'s Broader Impacts criterion (2008), and the Computer Science for All initiative (2016). Despite this long-standing yet evolving policy commitment to equity, inclusion, and capacity-building in science and technology, the US educational system has yet to sufficiently broaden participation in STEM (BPiS) to meet growing demand for advanced technology skills [1], [2].

This paper analyzes the application of Socio-Technical Integration Research (STIR) within an undergraduate computing and information systems (CIS) internship as a contributor to BPiS. It presents an extensive case study from the first Research Site in the first author's PhD dissertation [2]. The protagonists for the case study are A1, A2, and A3. As seen in the qualitative case study manuscripts, use of STIR broadened participation in the near term through improved persistence of A1, A2, and A3. In this case study, application of STIR also enhanced the three students' socio-technical decision capacity to benefit upcoming generations as they prepared to transition to the future workforce and/or advanced degrees. Using STIR led to "future-making" decisions and solutions delivery with broader societal impacts, such as equitably distributing internet connectivity and establishing information and data literacy to provide much needed access to resources for bridging the digital divide [3], [4].

Although this paper features one case study, the first author performed similar research studies at two additional sites altogether spanning three years of extensive research data collection and analysis. Participants in the larger, 3-year research investigation included 11 undergraduate engineering students [2].

This paper is divided into eight subsequent sections to articulate underlying research components and the case study: Problem Statement and Need; STIR Methodology and Protocol; Midstream Modulation Analytical Framework; Qualitative Case Study; Findings, Conclusion; Limitations, and Implications for Future Research.

1. Problem Statement and Need

This section discusses two problems, firstly BPiS shortfalls and secondly bridging the digital divide gap in education, the problem tackled by the three CIS students in this case study.

1.1. Systemic Cycle of BPiS Shortfalls

Historically, the BPiS problem is a longstanding and seemingly insolvable problem as described in the introduction, and specifically by the NSF [1]. It is both a societal problem and a technological problem that has not been previously viewed or treated as a system of interdependencies.

Partitioning BPiS into three stages aids in understanding the system cycle and the potential problems. In stage 1, active STEM students learn technologies in their field of study with very little or no consideration of societal impacts in their technical decisions. Upon completion of their studies, the students transition to the future STEM workforce. In stage 2, the workforce produces products that impact current and upcoming generations by perpetuating socioeconomic inequities, such as reduced accessibility to higher education. In stage 3, a subset of the upcoming generations become STEM students, but insufficient to meet the workforce demand.

This creates an ongoing systemic cycle where one problem or opportunity fuels another in a continuous loop. Challenges exist in each stage and each stage depends upon foundational principles, behaviors, and actions established in prior stages. Evolving behaviors and decisions of STEM students to consider societal impacts of their technology products can enable the future workforce and upcoming generations to break out of the problematic BPiS cycle of shortfalls.

1.2. Bridging the Digital Divide

Since the mid-1980's, disparities between schools with funding to invest in technology and others that did not, created a digital divide in education. Lack of technology such as infrastructure, devices, and internet services fueled the digital divide. Alongside insufficient technology, the need to address gaps in digital literacy and social learning became clear, especially after technology implementation [4].

According to the U.S. Census Bureau [5], within the neighborhoods served by Phoenix's major urban high school district, 20.1% of households are without an internet subscription, and for households that do have an internet subscription, 17% only have a cellular internet connection. While 94.6% of households have computing devices in the home, for 18.8%, the smartphone is the only computing device.

When the pandemic shut down K12 schools, many students in urban Phoenix did not have reliable high-speed internet or sufficient devices to school at home. Schools distributed thousands of devices and hotspots to students with no access to the internet to enable a rapid transition from school to home learning. Strategies included: setting up temporary hotspots; mapping community Wi-Fi points; and equipping buses with Wi-Fi to help fill short-term needs. It immediately became evident that a long-term solution was needed to bridge the digital divide for education in urban Phoenix. Over eighteen months, the City of Phoenix, an information technology (IT) architect at a local community college, the major high school district, and its feeder school districts partnered to design, fund, and develop a long-term secure wireless canopy. The first pilot supported a four-square-mile area. Expanding the secure wireless coverage and its implementation into student's homes became the next priority. Three challenges for the expansion and implementation included 1) a shortage of technicians skilled in the new technology; 2) how to establish connectivity using different types of devices suited to different housing structures; and 3) digital literacy to maintain and effectively use the connection.

2. STIR Methodology and Data Collection Protocol

A typical STIR research study lasts 8 or more weeks and involves multiple participants while they are actively engaged in projects in their work setting. Typically the participants are already experts in their field. Within an experiential learning context such as an internship, using the four part STIR protocol [6] an embedded social scientist (ESS) collaboratively dialogs with each engineering student (or STIRees) to investigate de facto values and awareness of societal dimensions within a technical assignment or project, as they are also learning the technology.

The dialog is a semi-structured discussion based upon the STIR protocol, adapted from [7], [8] and seen in Figure 1. The protocol employs a four quadrant diagram (Focus upper left; Considerations, upper right; Alternatives, lower right; and Outcomes, lower left) guides the discussion, with prompts from the social scientist as needed. Initially, the social scientist asks for an upcoming decision, opportunity, or problem to focus the STIR dialog. When crystallized by the STIRee, the social scientist 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 social scientist 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 social scientist summarizes key points highlighting any reflexive insights that represent changes to their de facto beliefs and values about human and societal dimensions in their project, and sometimes deliberate changes that result from earlier reflexive insights [7].

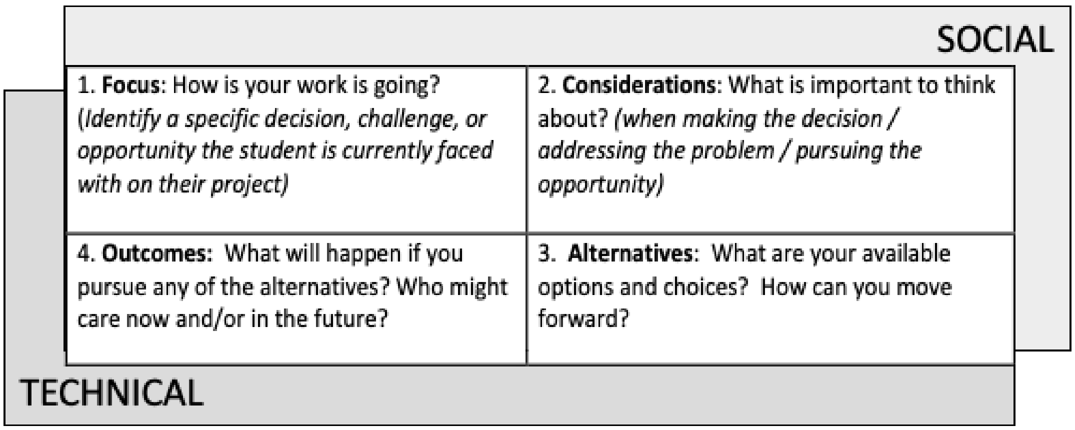

Figure 1. STIR Protocol and initial prompts. (Adapted from Fisher & Mahajan 2006, Schuurbiers & Fisher 2009).

The collaborative STIR protocol unpacks the context of decisions as they are being made, suggested, assessed and re-assessed. It can be a rewarding exercise for the STIRee and the STIR investigator to unpack the social in the technical together and both will gain knowledge through the process. Over time the dialogs can provide value to the STIRee through clarified systemic thinking about daily tasks, goals, choices, and expectations. Mapping and describing ordinary practices in the dialogs may also reveal how routine choices help reproduce existing structures and reinforce recurring dynamics, open or foreclose options for change, and amplify or silence concerns and uncertainties about potential impacts. This may develop STIRee's sense of agency in contributing to society and future imaginaries. Altogether the dialogs promote reflexive learning over time and may lead to integrating the exercise into regular practice, contributing to the STIRee's professional development.

The social scientist then uses midstream modulations [7], described next, to perform a time-sequenced analysis for each engineering student over the series of their STIR dialog diagrams and transcripts. The analysis identifies defacto, reflexive, and deliberate changes as defined below.

3. Midstream Modulation Analytical Framework

The concept of midstream modulation refers to alteration of ongoing technology development activities in accordance with broader societal goals, considerations, or influences. Changes are captured using the framework for identifying midstream modulations of technological trajectories [7] after project priorities have been set and before societal impacts are fully understood. As participants become more aware of the societal contexts in which they already work, midstream modulation refers to alteration of ongoing technology development activities in accordance with broader societal goals, considerations, or influences. In STIR studies, midstream modulations typically represent the micro-level analysis of data from each individual who participated in STIR dialogs. Pre- and post-study interview responses for each participant along with the investigator's notes are analyzed to assess changes in reflexive awareness of participants' social impacts in technology projects. This involves identifying baseline defacto (and possibly also reflexive, and/or deliberate) midstream modulations as defined below [7].

1. **De facto Modulation** – participants' decisions are influenced by existing human, social and material aspects that shape their technology projects.
2. **Reflexive Modulation** - participants become more aware of the role of de facto modulation in their technology decisions.
3. **Deliberate Modulation** - participants use insights from reflexive modulations to alter their decisions and practices.

A narrative summary of key changes for each participant across their pre and post interview responses and STIR dialogs is constructed and presented in a time-stamped tabular format. As mentioned previously the typical STIR research study involves multiple participants. Further analysis and comparison across individual results sometimes reveals patterns across the group.

4. Qualitative Case Study

This section details the research study conducted with three CIS undergraduates. Participants in this study included three engineering students in their second year who engaged in six pre/post semi-structured interviews, 12 STIR dialogues, 10 ethnographic observations, and who generated numerous project artifacts e.g., videos and documents.

Their community college CIS instructor, a Citizens Broadband Radio Service (CBRS) technology expert, devised a paid internship program to train students to the proficiency needed to address a subset of the three challenges described in Section 1.2. During their internship, the CIS students would: 1) undergo basic technology training; 2) test which Wi-Fi receivers and specific configurations worked to detect signals from the secure wireless canopy in different types of housing structures; and 3) develop instructions for easy setup and maintenance by high school students.

As part of their internship, each CIS student worked on a mini-project for bridging the digital divide, which required learning a new technology. Concurrently they participated in a STIR research study. During STIR dialogs with the social scientist, the students gained reflexive awareness of social impacts in their technology projects and sometimes made deliberate decisions to address them.

The CIS students also emphasized the importance of helping upcoming generations avoid the types of socioeconomic challenges they previously faced, articulating potential ways to address these challenges. Then they built proactive features into their project solutions.

4.1. Background and Demographics

Collectively, the case study participants represent multiple intersectional identities including gender, race/ethnicity, first generation, economically disadvantaged, and non-traditional student status (e.g., enrolled part time, with adult responsibilities, not fresh out of high school). The group included one Hispanic male (A2) with young children, working full time in the service industry, first generation to college, with seven brothers and sisters, and an ESL speaking mother. It also included two Africans, one female with a young child (A3) and one male (A1), both working part time in non-STEM jobs, and who spoke English as a second language (ESL).

The case study in this paper focuses initially on detailed results for A2. It then presents a subset of results from A3 and A1, sufficient to identify and discuss patterns.

4.2. Recruitment

A prior relationship with the CIS instructor existed from research for an NSF-sponsored award focused on work-based experiential learning for CIS students. This knowledge facilitated identification and establishment of the 2-year HSI as a research site. It also supported recruiting participants for the STIR study.

First the social scientist obtained permission from the research site IRB and her ASU IRB to conduct the study. Next the social scientist requested the internship coordinator at the research site who already interacted directly with candidate engineering students to send the recruitment email. Recruitment targeted students from groups traditionally underrepresented in STEM, specifically in CIS majors who had completed the first year of courses and were about to begin an 80-hour internship spread over 12-weeks. Recruiting began one month prior to the start of the internship. Participants were considered selected after they consented and then were assigned anonymous identities: A1, A2, and A3.

4.3. Participant Expectations

All participants were informed that the study would involve meeting with the social scientist to discuss upcoming decisions of their choice related to their project or other areas. They were informed that participation would take up to six hours alongside their 80-hour internship and that their participation was voluntary. They were also informed that any interactions with the researcher would be confidential and scheduled at their convenience. In terms of benefits, students were informed during recruitment that potential benefits included professional development and mentoring during regular 30 minute dialogs with the social scientist who also had professional engineering experience in industry.

4.4. Results

Over the course of their project, in individual STIR dialogs with the social scientist, each intern explored within specific technical decision contexts what they viewed as important considerations in making the decision, what alternatives they might pursue to move forward, the possible outcomes from pursuing one or more alternatives, and who cared about each outcome both now and in the future. Drawing out the considerations is where, through guided reflection, the integration of social dimensions sometimes occurs, as decision makers begin to critically question why they are doing what they are doing. Engaging in STIR helped students think about a broad range of considerations. Enumerating alternatives potentially integrates ways of addressing social considerations that are more deeply ingrained with where they are at in the technology development process. Revisiting the prior dialog at the beginning of each new STIR session to query progress can reveal explicit SocioTechnical knowledge gains through STIR, if these gains have occurred through reflexive insights and/or deliberate actions.

4.4.1. STIR Dialogs

This section portrays an example of using STIR during the Digital Divide (DD) internship, using STIR dialogs with one participant in this case study, Participant A2. The modulation sequence tables derived from STIR dialogs for each participant will be presented below (in section 4.4.2) .

Sample STIR Dialogs

At the time of the STIR study, Participant A2 was in his second year of CIS at the 2-year Hispanic serving institution and passionate about technology, specifically cybersecurity.
In the semistructured pre-study interview, a clear de facto value surfaced, when A2 responded to an ESS question.

> ESS: What other types of considerations do you think should play a role in technology decisions about the project that you are working on?
> A2:"how to communicate instructions to someone [who is asking me for help]. I usually explain things step by step, then show them how to use it."

By the second STIR dialog (Figure 2), A2 was working on his DD project and chose to focus on the powerpoint instructions and video he was making to show a high school student how to set up DD equipment. When prompted for considerations in making the instructions, he brought up a new element that it was "important to consider the perspective of the high school student" Related outcomes were "Students understand what not to do, what might cause damage" and "Students form a sense of caring for the device, how to take care of it."

Figure 2: Second STIR Dialog with A2

The followup discussion for the second STIR Dialog with A2 went as follows:

> ESS: When we did our most recent STIR session a few weeks ago, you were just getting started with the instructions and the video

<ESS hands A2 the above STIR diagram; he looks it over closely>

ESS: How are things? How is your work on the instructions going?
A2: Things are going great. I am keeping the same device names for now, HS students need to know which pieces come in the box and what to use them for. Also I need to keep referring to them consistently.

ESS: Did any of the considerations or alternatives from the second STIR play into your work and decisions?
A2: I used critical thinking to distinguish how I described the adjustment clamp based on what it does (not just calling it side clamp part 2).

ESS: Did student perspective play a role in that decision?
A2: Yes, but it also applies to adults

ESS: Anything else?
A2: I also thought about how to make it precise, simple and compact, so they get all of the information needed to do the job. I put myself in their shoes, doing it the first time. I'd be messing with it, taking it apart,[if I were in their shoes]. So I wanted to, for the crucial parts, have them understand what might cause damage to the part, for example, if they unscrew the cap, they will expose the prongs that could easily break and they don't need to [unscrew that cap] as part of the setup. I focused on recommended procedures.

ESS: Could you provide an example of a recommended procedure?
A2: Where to put it to get a better signal, higher up, near a window, facing the direction of the nearest tower (the closest school, about a 5 mile radius for middle school (MS), but high school (HS) students typically travel further to their school).

ESS: What if you have a family with both MS and HS kids? That's something you might have to convey in the instructions and you may not have all that information at this point.
A2: You could put some kind of a note in there to whoever's going to finalize it for particular students that they need to cover this possibility for families with both MS and HS students, the closest school will likely be the MS.

ESS: Anything else?
A2: Step by Step directions for students, I am doing that pretty well. What not to do, like not setting it on the edge of a table.

ESS: Do you think going through the STIR process impacted the way you might have done what you're doing so far, or would you have done the same thing anyway, without STIR?
A2: This process it's really helped me out when I'll talk to you and doing this because you provided me feedback on it. And so that actually did affect me when I was making these powerpoints, also though -- when I was thinking it through.

In the third STIR dialog with A2 (Figure 3), a strong technology focus dominated (how to assemble the equipment) because A2 was in the middle of creating video and textual instructions from hands-on experience with the equipment which was the primary assignment at this phase of the internship. The STIR dialog initially <u>focused</u> on reworking the instructions for a twelve year old, because MS's were feeders to the HS's. Grammar was a very important <u>consideration</u>, especially for an ESL speaking child, for their understanding. When enumerating <u>outcomes and who cares</u>, a light bulb went on, when A2 mentioned parents and formed a connection to grammar and ESL <u>considerations</u> as important for parents too.

> A2: Parents care about understanding instructions, they might have to help with or do the setup. Many do not understand English well (in my experience). Good instructions help them learn English. A Spanish translation would also be very helpful. I highly recommend it. I'd be willing to help with a Spanish translation.

Figure 3: Third STIR Dialog with A2

4.4.2. Midstream Modulation Analysis

This section presents modulation sequence tables and analyses from STIR dialogs, beginning with A2. The modulation sequence tables and analyses for A1 and A3 are also presented.

<u>Participant A2's Modulation Sequence</u>

The example in Table 1 represents a series of midstream modulations that emerged over multiple STIR dialogs as we discussed A2's project. In the modulation sequence, A2 expanded upon his *de facto* attitudes about communicating and listening instead of making assumptions about what solutions high school and middle school students need (Table 1: T0) by reflecting that he needed to further contextualize the instructions to student perspectives (Table 1: T1), then ideating ways to bring in those perspectives (Table 1: T2).

Throughout the temporal sequence, the reader can see how A2's de facto ways and assumptions reflexively deepened to consider high school student and parent perspectives. His offer to work on a Spanish language translation for the equipment setup instructions (video and text) represents a deliberate change (Table 1: T3). Later, at the final group report out to the high school district implementation team, he recommended language translation during his presentation (Table 1: T4). In the ensuing discussion, the team learned that the four interns collectively spoke seven languages which mapped to demographics of the high school students receiving digital divide equipment. The district team acknowledged the value of performing language translation.

Table 1: Participant A2's Deepening Awareness of Communication in Societal Contexts

Time	Excerpt / Observation	MM	Dimension
T0	A2 considers what skills or equipment clients "have or don't have," and afterwards will "Then just communicate with them." Communication is a straightforward process of "Provid[ing] them with what they need, explain[ing] basics step by step, then showing how to use it."	De facto baseline	Technical
T1	A2 realizes that "It is important to consider the perspective of the high school students when making a video and slides to set up equipment for the digital divide at their house."	Reflexive Learning -Context	Technical, Social
T2	A2 realizes that interacting with clients will aid learning about their perspectives and begins to develop creative ideas for this purpose: "I need a high school or middle school kid to try out my instructions. Maybe we can get some students from [anonymized] high school to come over and see our demo's then do some hands-on."	Reflexive Learning -Ideation	Social, Technical
T3	A2 realizes that clients operate in a social context: "Parents…might have to help with or do the setup." However, "Many [parents] do not understand English well in my experience." Therefore, "A Spanish translation would…be very helpful." A2 then commits to a new task: "I'd be willing to help with a Spanish translation."	Deliberate Adjustment-Ideation	Social
T4	At the group report to the implementation team, the interns recommended language translation. The four interns collectively speak 7 languages which all map to demographics of the high school student clients receiving digital divide equipment. The implementation team agreed with this direction.	Deliberate Adjustment -Expansion	Social, Technical

This example also shows the interaction of cultural experiences, sense of responsibility, and autonomy in presenting the idea to the district team. Enumeration of future possible outcomes expanded upon prior notions of how to explain step by step instructions to enrich the experiences of his clients, when he applied his own cultural assets based on personal experience in his family. In a traditional internship with a focus primarily on technological learning, the opportunity to realize, recommend, and apply these unique skills towards societal benefits might not have been recognized or supported.

The modulation sequence tables for A1 and A3 follow, along with supporting highlights from their STIR dialogs.

<u>Participant A1's Modulation Sequence</u>

The modulation sequence from A1 shown in Table 2 and the accompanying narrative illustrates a progression from a simple understanding of the digital divide from a social and technical standpoint (Table 2: T0) to a more specific plan to enrich the delivery of technical instructions to the solution recipients (Table 2: T1-T4).

Table 2. Participant A1's Increased Sophistication for Collaborating and Including Clients

Time	Excerpt / Observation	MM	Dimension
T0	First time A1 is hearing about digital divide but he thinks it is about social divides and a work project.	De facto baseline	Social, Technical
T1	I'd consider the people who need it most. And I would want to include them. I would want to know what they need internet access for: e.g. school, work, business. It's hard to see what they want, they might say something, if we make eye contact I can tell better.	De facto	Social
T2	Our group will come up with new and better ideas, learn from each other, come together as a team, and help each other do their jobs. We want to do the job right while also learning.	Reflexive Learning - Reflexive	Social, Technical
T3	A new alternative arose when discussing outcomes that went beyond the ways interns were asked to convey instructions to high school students. The idea was an interactive webinar with the group of interns explaining/ showing, after HS students get their devices then have them try it during the webinar and ask questions. This could be longer lasting and others could benefit from the reenactment.	Reflexive Learning - Ideation, Context	Social
T4	A1 developed the slides that he specified as an alternative for what he was working on -- to show high school students how to set up and care for a digital divide device that would be shipped to their home or sent home with them from school. A1 also rehearsed his "how to" video demonstration for the device.	Deliberate Adjustment - Behavioral	Social, Technical

From the beginning of the study, beyond learning the technology and societal context of the digital divide (Table 2: T0), A1 showed sensitivity to human and social dimensions for engaging with customers in the community, "I'd consider the people who need it most," "what they need internet access for," and "if we make eye contact I can tell better" (Table 2: T1). As the semester progressed, when we discussed completing an assignment during one of our STIR dialogs, A1 realized working together was better than working alone and *reflected* "our group will come up with new and better ideas, learn from each other, come together as a team, and help each other do their jobs." Then he added "we want to do the job right while also learning." Both remarks show *reflexive learning* through broadening of the project to include teamwork as a way to improve outcomes. The second remark also shows that A1 realized learning is iterative and ongoing – and it is possible and important to do the job right while learning (Table 2: T2). Later in a STIR dialog, when A1 and I were reasoning through his hands-on project to explain to local high school students how to set up the box [BEC digital device, after they have it], a novel idea arose (Table 2: T3), as can be seen in the dialog excerpt reproduced next.

> ESS: What are some different ways you could provide the how-to instructions?
> A1: I could show them in a video, either recorded or live in person face to face. And let them try it too, after they watch me, then provide feedback to do it right.
> ESS: That's a good idea. What else might you try?
> A1: I could make Google slides with lots of pictures and only some words
> ESS: Which of one of these ideas do you think you will do?
> A1: The Google Slides and also a recorded video. If we do zoom, I'd let them show me, after I showed them.
> ESS: What are some of the possible outcomes?
> A1: For Google slides, they might have more questions or they know how to set up the box where they live or somewhere else if they moved, or if they got another box of a similar type.
> A1: for the video, teaching them step by step might help them to understand faster, and if we had a live webinar with more than me explaining/ showing, after the high schoolers get their devices, and if they had questions, they could try it too, after we show them, and we would provide interactive feedback. [The ESS added the interactive webinar with multiple people as a fourth STIR Alternative]
> ESS: And what might be an outcome of the webinar?
> A1: It would be longer lasting and for more people to benefit from seeing it.

The above excerpt illustrates *reflexive learning* where A1 deepens his earlier conceptualizations of team work to the *context* of his current project to enable an *idea* that goes beyond what he was originally asked to do: to hold and record an interactive video 'how to' session with high school trainees. After our STIR dialog, A1 went on to develop the google slide instructions (STIR Alternative 1) and video recording (STIR Alternative 2) for the next few days as observed by the ESS and verified by final artifacts uploaded to the Internship Shared Drive (Table 2: T4). These actions represent *deliberate behavior* adjustments that tie to earlier reflexive moments.

A1's ideation, while somewhat ambitious considering the time remaining in the project, shows sensitivity to normative social influences because it is future looking, could benefit more downstream trainees, and increase value beyond a static how-to video recording.

<u>Participant A3's Modulation Sequence</u>

The modulation sequence in Table 3 captures key moments during STIR sessions with A3 that demonstrate deepening awareness for community context and human dimensions while also learning the technology. The items in the sequence represent modulations, namely, changes in reflexive learning about the context and content within the project followed by subsequent actions and practical adjustments. The ESS identified a de facto modulation in A3's pre-study interview, that her personal opinion would not impact technology decisions, unless the technology might cause harm, in which case her intervention might be needed Table 3: T0).

Table 3. Participant A3’s Deeping Awareness for Community while also Learning Technology

Time	Excerpt / Observation	MM	Dimension
T0	A3’s personal opinions on societal considerations "probably won't impact [technical] decisions…as long as it is not bad for them."	De facto baseline	Social, Technical
T1	"Community - high schoolers ... get benefits - connection to the internet, get schoolwork done outside of school, and motivation." [Shows expansion of A3’s conception of the community context beyond T0 to include positive benefits from her technical decisions.]	Reflexive Learning -Context	Social, Technical
T2	"Where High School students live, where their school is" [Shows expansion beyond T1 to include socioeconomic factors in A3’s technical decision making].	Reflexive Learning -Context	Social, Technical
T3	"I would start with a personal understanding / story to set the stage," [Shows broadening of a technical task to include reflexivity and social dimensions].	Deliberate Adjustment -Strategic	Social
T4	"Community, school district, parents, and students care because it helps them with schoolwork and life." [This is an expansion beyond T0 and T1 that includes future prospects in addition to near-term benefits.]	Reflexive Learning -Context	Social

Later, during a STIR dialog, the ESS and A3 discussed how she should finish digging into the technology landscape for the digital divide. Important considerations included: Understanding the technology, the Digital Divide goals and "Making sure I do it right." The dialog partners talked about alternatives for how to do the task: Using computers, Searching the web, Reviewing and sharing PowerPoints, and Reading emails w/ instructions and links. The outcomes that we discussed for all the alternatives were: Success in getting work done (A3 and the group), Learning (A3 and the group) and (the instructor) applies our ideas in the Digital Divide solution for high schoolers. As can be seen in the following excerpt, A3 broadens her notion of moral agency for a technology development to include not only preventing harm but also improving the technology to better serve members of the community.

> ESS: Who else might care about your successful outcomes with the Digital Divide?
>
> A3: The Government is proud of the accomplishment because their investment pays off... [also the] Community - high schoolers care because they get benefits: connection to the internet, get schoolwork done outside of school, and motivation.

The ESS identified the latter remark as a Reflexive modulation (Table 3: T1), because A3 realized something she had not articulated before, namely, that her learning the technology and “getting it right” by pursuing alternatives 3) and 4) could impact the community and high school students in positive ways, an expansion on the de-facto remark during the pre-interview that her personal opinion would not impact technology decisions, unless the technology might cause harm, in which case her intervention might be needed.

A subsequent STIR conversation focused on a technical deliverable, creating instructions to explain how to set up and care for an DD device at home. Initial considerations were technical, e.g., SIM card, device, but after the ESS continued to probe, A3 mentioned a socioeconomic consideration:

ESS: Are there any other considerations?

A3: Where they live, where their school is.

A3's latter comment considers socioeconomic factors, as many of the families in surrounding neighborhoods are below poverty level incomes. Some live in apartments, and many are renters. The ESS identified this as Reflexive Learning (Table 3: T2) in the context of the families receiving the technology devices, and how it impacts which device they are assigned, where they put it in their house, and how they orient it to pick up the WIFI signal. When the dialog partners discussed alternatives, the usual ways of using pictures, words, and a video were offered. Again, only after the ESS continued to probe (following the STIR protocol) did A3 then mention a novel and interesting alternative to personalize the instructions by adding an example from her lived experience:

ESS: Are there any other ways you can think of to do this?

A3: Figure out the steps by working with the pieces and parts of the device hands on, then develop the instructions.

ESS: Anything else?

A3: I'd like to start out the instructions with a personal understanding to set the stage.

Adding "personal understanding" suggests that A3's conception of the instructions has broadened to include not only technical but also social dimensions. This is a form of learning that demonstrated a deliberate adjustment that was strategic (Table 3: T3) because A3 planned to put a bit of herself and her story into the video deliverable to make it more relatable to high schoolers. As seen below, in discussing outcomes, two possibilities arose, high schoolers can set up the device or not.

ESS: Who cares about whether the high schoolers can set up the device?

A3: The community, the school districts.

ESS: Who else cares?

A3: The parents care.

ESS: Why might the parents care?

A3: It helps their kids with completing schoolwork and in fulfilling their life.

A3's explanation of why parents might care represents Reflexive Learning (Table 3: T4), for it shows deepened sensitivity to the digital divide context and longer-term benefits to humans and society. It is part of a continuing pattern of deepening sensitivity to social considerations and her own role in technology decisions that has emerged from the collaborative STIR dialogs between A3 and the ESS.

Examples from two additional research sites and their in depth analysis are available in the first author's dissertation [2].

4.4.3. Post Study Interviews

Two questions from post study interviews with A2, A1, and A3 that illustrate results for persistence and consideration of social impacts are presented in the next two subsections. Each subsection begins with the assessment question followed by results from each participant before or during the internship and their response to the post study question.

4.4.3.1. Persistence

To assess persistence, in the post-study interview all three students were asked ***"What has been the impact of the internship on your persistence in computing and information systems[1]?"*** The persistence question was asked at the close of the internship and again two years later. Each student's response to the question follows an example of a persistence challenge experienced earlier during the internship.

<u>Participant A2 Persistence</u>

Initially as the internship began, when A2's regular job interfered with live attendance in lab sessions during the day, A2 watched recordings at night and felt he was getting behind. In our STIR's during the discussion of alternatives, together we devised a way to ask questions and keep up. In the next STIR, he reported acting upon the prior alternative with the outcome: "I am getting clearer on the foundation."

At the end of his internship, A2 responded to the persistence question:

> A2: I would say learning new technologies on the job and adapting what I learned to a new job or new problems. Before I was concerned when I start a new job, will I be able to do this job...come up to speed quickly enough?

Two years later his persistence is very tangible:

> A2: I am still a student, now pursuing a bachelors, remotely, and hope to graduate in the Spring. I also work full time in an IT related job providing services for the banking industry.

<u>Participant A1 Persistence</u>

In an early assignment A1 researched the CBRS technology and reported his findings alongside a teammate, letting her present his work after she presented hers. Then after a STIR dialog where we discussed this, he stepped up during a subsequent presentation and verbalized a major milestone that he had met, also summarizing the outcome. Consequently A1 received visible praise from the instructor. The social scientist categorized the series as an example of reflexive learning and resilience that contributed to ongoing persistence during the internship.

[1] Computing and information systems (CIS) is a specialization of Information Technology (IT)

At the end of his internship, A1 responded to the persistence question:

"Yes definitely, I want to be an IT worker. The digital divide internship was the first real experience. I was already studying IT, but this was a real paying job." Immediately after his internship, A1 transitioned out of his work study position as a receptionist in the English Department to a CIS lab position at his college, applying skills learned in the internship.

Two years later his persistence is very tangible:

He finished his CIS associate degree at the 2-year college and planned to apply for admission to a CIS bachelor's program at a 4-year university.

Participant A3 Persistence

During her internship A3 worked nights as a caretaker and sometimes faced childcare challenges causing her to miss some of the onsite labs. We talked about this in one of our STIR dialogs. Later she reported, "It took some time to put together all of the technology pieces, but after [the instructor] covered architecture diagrams, things clicked together." The social scientist categorized the outcome as an example of reflexive learning that contributed to ongoing persistence during the internship.

At the end of her internship, A3 responded to the persistence question:

Yes. I remember the instructor telling us his story as an immigrant, how he got started in IT, and how he is still growing. When people tell me their story it gives me hope of going further. It kept me going and inspired me to push more, to be like that. Knowledge and learning are important. But I really value the people, having the conversations, and learning from each other.

Two years later her persistence is very tangible:

After graduating from the 2-year HSI, A3 graduated with her bachelors degree from a local university. Currently she is pursuing her Phd in CIS.

Examples from two additional research sites and their in depth analysis are available in the first author's dissertation [2].

4.4.3.2. Consideration of Social Impacts in Technical Decision Making

To assess consideration of social impacts in making technical decisions, in the post-study interview each of the three students was asked ***"If known, please describe any societal impacts and considerations that are specifically linked to the internship"*** The societal considerations question was asked at the beginning and after the internship. Each student's pre/post response to the question follows in Table 4.

Table 4: Pre/Post views of societal considerations and impacts of the internship deepened

	Pre-study Response	Post-study Response
A1	Yes, first to learn what the digital divide is, then how to gain more experience as students in a real world project.	The community needs this technology, poor families need help. This will help the community to grow and provide students with internet access to get education.
A2	Just beginning this internship and learning more about the digital divide.	Provide free wifi to Elementary, Middle, and High School Students, especially people who are struggling. By providing computer and wifi resources, we give everybody a fair opportunity to their education and a better chance to achieve their goals.
A3	Yeah sure, I chose to be in this internship because I was interested in it, interested in tech. We live in it, in school, in life, always learning new things.	Develop a new technique to help students with their school program to help with success in their life. Especially people with low income.

Before the internship, the interns expressed their desire to learn about the digital divide and gain experience. After the internship, responses were characterized by helping the community and providing fair access to education.

Examples from two additional research sites and their in depth analysis are available in the first author's dissertation [2].

5. Findings

Drawing on common patterns identified across STIR dialogs, modulation sequences, pre and post-study interviews, and ongoing observations throughout the case study, next we highlight three findings relevant to BPiS and the role STIR can play in supporting BPiS. The overall finding from this case study is that **STIR amplifies the potential for work-based experiences such as internships to broaden participation in STEM.**

5.1. Modulation sequences

All three participants experienced modulation sequences and the modulations that adhered to the midstream modulation framework, demonstrating that modulations follow a sequential process in which reflexive insights are an important precursor for deliberate changes in decision making during technical projects. This can be seen in the fact that the three participants had reflexive modulations that served as a catalyst for their changes (as shown in Tables 1, 2, and 3). For instance if A2 had not realized his experience with an ESL speaking mother who needed a Spanish translation to help her children with math, and tied it to his digital divide project, he would not have suggested translating his instructions to Spanish. This finding concurs with findings from numerous other STIR studies [9], [10], [11]. The fact that STIR dialogs produce consistent outcomes in a discernable pattern demonstrates that it can be part of a systematic HIP that enhances technical internships in ways that support BPiS.

5.2. Persistence

A1, A2, and A3 all experienced moments early in the internship and showed resilience in working through challenges associated with learning the new technology. Together we worked through the challenges in some of our other STIR dialogs. Two years later during a post-study longitudinal interview they showed ongoing persistence in related academic studies and in some cases their careers as described in section 4.3.3.1. This finding supports STIR's contributions to persistence, which is a known enabler to broadening participation in STEM [12] and in particular CIS, because A1, A2, and A3 each completed their internship, continued their CIS studies, and transitioned from service oriented jobs to CIS-related jobs.

5.3. STIR Contributions to BPIS through SocioTechnical Learning

The primary emphasis prior to incorporating the STIR dialogs centered on learning the technology to bridge the digital divide and applying learning through hands-on interaction with the technical equipment. After one or two STIR dialogs, considerations and outcomes gradually took into account providing equitable access to education resources in the nearby economically disadvantaged neighborhoods. All interns experienced reflexive learning and behavioral adjustments from their participation in STIR dialogs. Modulations as different types of reflexive learning and deliberate adjustments were identified by the social scientist as summarized next.

For example, A1 demonstrated increased sophistication for collaborating and including clients to better serve them via contextualized reflexive ideation that led to a new alternative well beyond the ways interns were asked to convey instructions to high school (HS) students. His idea was to host an interactive webinar where the group of college interns explain and show the HS students how to set up and use their devices with questions from the HS students. Then after the HS students got their devices, they could practice device setup and usage during another webinar and ask more questions. He remarked, "This could be a longer lasting benefit for others." A1's contextualized ideation, while somewhat ambitious considering the time remaining in the project, shows deepened sensitivity to social influences and impacts because it was future looking, which differed from his usual thinking, could potentially benefit more downstream trainees, and increase value beyond a static how-to video recording.

Throughout A2's modulation sequence, the reader can see how A2's defacto ways and assumptions reflexively deepened to consider perspectives of high school students, middle school students, and parents. His offer to work on a Spanish language translation for the equipment setup instructions (video and text) represents a deliberate change.

A3 demonstrated deepening awareness of the community context (socioeconomic factors) related to her technical decisions. Later, A3 demonstrated a deliberate adjustment in the form of a strategy to apply to her next solution iteration. This showed a continuing pattern of deepening sensitivity to human and normative social considerations and her own role in technology decisions that emerged from the collaborative STIR dialogs between A3 and the ESS.

In all three participants, STIR was shown to provide contextualized support for individuals from groups traditionally underrepresented in STEM during the internship. The contextualized support was in the form of guided dialogical interactions that linked to reflexive learning and deliberate changes in students' material practices and behaviors, also referred to as modulations.

During regular STIR dialogs, discussing how to learn more effectively, practice a particular skill, or what was involved in making a decision 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 so led to increased confidence and further reinforced SocioTechnical Learning.

6. Conclusion

This study found that STIR amplifies the potential for work-based experiences to broaden participation in STEM**.** This research involved teaching and mentoring active CIS students to think and act differently as they learned the technology and its applications. They were shown to have developed an awareness of societal challenges and to have considered technology and social impacts when developing solutions, even sometimes changing their practices. STIR served as a blueprint that helped students reason through socio-technical decision-making in their projects to benefit humans and society and to avoid unintended consequences. More generally, we found that using STIR alongside work-based experiential learning by undergraduate STEM students can build up social and technical learning over time in the context of their technology projects, enhancing the state of the art for undergraduates' experiential learning in technical fields. The term SocioTechnical learning captures this phenomenon, helping to make sense of the empirically observed steps in this case study: learning technical skills, learning to reason about societal contexts of technology decisions, and applying both types of learning in decision-making contexts.

In conclusion, the combination of work-based experiential learning and STIR was found to increase persistence, and more generally to contribute to Broadening Participation in STEM [12], [13], [14], [15], [16]. In the short term participants in this study completed their internship and transitioned to jobs or higher education in CIS related fields. Participants also expressed aspirations to continue to influence and bring along others in CIS and adjacent fields.

7. Limitations

This research examined internship experiences at a single institution, with three undergraduate students from underrepresented minorities in CIS. The sample size for this study was smaller than sufficient for a statistically significant analysis. The findings from this case study apply to a specific context, and cannot be generalized to other contexts, such as 4-year institutions. However, as presented in the first author's dissertation, a larger study comprising three such case studies conducted over three research sites with similar technical fields do apply. The participants in the first and third studies consisted of under represented minority groups in STEM. It is worth noting that the second study included two majority group students although one was female. Moreover, some ninety-five world-wide STIR studies beyond this one have examined different technical fields at different types of organizations, including industry and academic labs at 4-year institutions, with participants representing additional typical demographics, including the White non-Hispanic majority group. As previously mentioned, the modulation sequence findings from this case study are consistent with these other STIR studies.

While not all of the other STIR studies took place in an engineering education context, several of them did, either in engineering laboratory research projects, for instance [6], [7], [8], [9], [11], or in larger classrooms with STEM students working together in groups, for instance [17], [18].

Therefore, the evidence to support other engineering education contexts, in different technical fields, with additional participant demographics, and different types of institutions such as 4-year universities and colleges has not been analyzed here.

Scaling a study such as this to a larger Cohort of CIS and or engineering students in group settings is required to achieve the needed BPiS impact. It is not clear that there are sufficient certified STIR practitioners to kickstart this endeavor due to the need for multiple days of training and additional practice with an experienced coach prior to facilitating STIR dialogs. It is unclear whether faculty or supervisors responsible for internships and other forms of experiential learning would be willing to undertake the required professional development. Even if they completed STIR training, STEM faculty, advisors, and student uptake and use of STIR to contextually support Broadening Participation in STEM is also uncertain.

8. Future Use of STIR Research

Recommendations and practical tips for engineering educators to explore the potential to embed findings within their pedagogical strategies include:

- Touch bases with the authors about using STIR or becoming a STIR research site.
- Attend a 2-3 day STIR basic training bootcamp to learn about STIR concepts and tools. Then practice STIR with a coach over the next few weeks to become a STIR certified practitioner. Optionally you may want to practice STIR later with someone you know, before using it with your students.
- Start with the standard prompts included at the top of each quadrant of the STIR protocol.
- You don't need to perform a full modulation analysis to use the STIR protocol, unless you want to perform a research study. It is recommended to incrementally trace modulations while in the field to inform subsequent STIR dialogs. If desired, workbook templates are available to organize the "data" in preparation for subsequent dialogs or formal modulation analysis.
- Use STIR during office hours with your students.
- Use STIR with your teaching assistants and/or colleagues to devise considerations, approaches and which option(s) to pursue in the course pedagogy.
- Consider tying STIR to ABET outcomes, especially criterion 3 which defines student outcomes as a set of seven skills and abilities that graduates from engineering and technology programs must possess. These outcomes focus on complex problem-solving, design, communication, teamwork, ethics, experimentation, and lifelong learning, ensuring graduates are ready to enter the profession. Outcome 4 in particular emphasizes the "ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts [19]."
- Become familiar with STIR approaches that engage larger groups such as those used in CAER [18] to facilitate group STIR sessions with your students.
- Instead of one-on-one facilitated STIR dialogs with students about their daily activities, conduct weekly 1-2 hour STIR focus group discussions where students discuss 'what-if' scenarios based on historical examples [17]. Each week, one student delivers a short presentation about a historical example, after which the focus group engages in a facilitated STIR dialog.
- Arrange for a STIR bootcamp with your students by a STIR certified practitioner.
- Divide your class into groups of 4-6 students. Set aside 15 minutes. Display a STIR protocol diagram, share a template with your students and have small groups of students use it. Each time there will be a STIRer and a STIRee: Rotate among student pairs in the group (likely 1 STIR session per class). Have the STIRee choose a problem or opportunity they would like to discuss. The STIRer walks the STIRee around the four quadrants using the standard prompts included at the top of each quadrant, and writing

STIRee responses. The rest of the group observes and learns, the STIRer summarizes key points, then the STIRee and the rest of the group reflects upon the overall outcome of the STIR dialog, and its pro's and con's (both in execution and the content produced).

- Consider including career workshop modules as part of your internship, project-based learning, and/or capstone courses. Incorporating STIR dialogs 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.
- Another scenario is to bring in speakers from local companies to the classroom. Don't ignore personal networks as an initial source for finding industry speakers. 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, alternatives, and desired outcomes. Such industry engagements could lead to mentoring relationships, targeted workshops, or future internship opportunities.

Acronyms

Acronym	**Definition**	**Acronym**	**Definition**
AS	Associate in Science	HSI	Hispanic Serving Institution
BPiS	Broadening Participation in STEM	IT	Information Technology
BS	Bachelors in Science	K12	Kindergarten through 12th grade
CAER	Creative Anticipatory Ethical Reasoning	NSF	National Science Foundation
CC	Community College	NASEM	National Academies of Sciences, Engineering, and Medicine
CIS	Computing and Information Systems	STEM	Science, Technology, Engineering and Mathematics
CIT	Computing and Information Technology	STIR	Socio-Technical Integration Research
DD	Digital Divide	URM	Underrepresented Minority
ESS	Embedded Social Scientist	WBEL	Work-based Experiential Learning

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