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# Challenges of peer instruction in an undergraduate student-led learning community: bi-directional diffusion as a crucial instructional process

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**Abstract** Learning communities (LCs) can provide authentic, social learning experiences but require an extensive amount of time and effort to orchestrate, often more than instructors can provide in typical university courses. Extracurricular, undergraduate, student-led learning communities (SLLCs) overcome this cost through volunteer peer-instructors. Unfortunately, LCs theory is based exclusively on teacher-led LCs. Here we ask *what instructional processes emerge in SLLCs?* We conducted a qualitative case study of SLLC student leaders' attempts to teach a project management practice (StandUp) to student innovation teams. We found that instruction in SLLCs takes the form of a bi-directional diffusion process, in which peer-instructors influence students' decisions about what practices to participate in, and students influence peer-instructors' decisions about advocating for practices. Three major findings support the bi-directional diffusion model. First, students' participation in StandUp hinged on whether they saw the practice as valuable with respect to their social, learning, and/or performance goals. Second, peer-instructors struggled to persuade and scaffold students to participate in StandUp. Third, students influenced peer-instructors to stop advocating for StandUp. The bi-directional diffusion model highlights the practical importance of persuading students to participate in the community's practices. The model suggests that we might support peer-instruction by promoting peer-instructors' content knowledge about practices, their persuasion skills, and their motivation to advocate for practices.

**Keywords** Learning communities · Peer instruction · Diffusion · Extracurricular learning environments · Authentic learning environments · Peer learning

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## Introduction

Extracurricular, student-led learning communities (SLLCs) can provide undergraduates with opportunities to develop problem-solving abilities by having relatively experienced students volunteer as peer-instructors for less-experienced students. For example, Engineers for a Sustainable World teaches engineering and sustainability (Dale et al. 2015), the Roosevelt Institute Network teaches policy analysis and advocacy (Roosevelt Institute 2016), and Design for America teaches social entrepreneurship (Gerber 2014; Smirnov et al. 2017). These 3 networks include 216 SLLCs, which are located within universities and have reached more than 10,000 students over the last 15 years. Students in these programs have developed new sustainable technologies, implemented new environmental policy, and created venture-funded startups.

SLLCs have spread quickly to many universities by using peer-instructors rather than professional instructors. However, we know little about whether and how SLLCs address the inherent challenges of learning communities (LCs), such as motivating students to learn new problem-solving practices, and what role peer instruction might play in addressing these challenges. Recent calls in this journal have emphasized the need to advance scholarship on LCs, specifically new kinds of LCs such as SLLCs (Ben-Zvi et al. 2015).

LCs have theoretical foundations in constructivism (e.g., Bielaczyc and Collins 1999; Zhang et al. 2011), and situated learning theory, especially communities of practice (CoPs; e.g., Brown and Campione 1994; Fischer et al. 2007). CoPs are groups of people who share practices, which they continually generate, apply, and spread; CoPs are sustained by legitimate peripheral participation, a process in which newcomers increasingly identify with the CoP, and increasingly generate, apply, and spread the CoP's shared practices (Hoadley 2012). For our purposes in this paper, we define LCs as communities of practice (CoPs) that are intentionally designed to promote learning.

Previous research on LCs has almost exclusively studied teacher-led LCs (e.g., Bielaczyc and Collins 1999). Unfortunately, theories of how instructional processes work in teacher-led LCs probably do not apply to SLLCs. For example, SLLCs rely on untrained peer-instructors who may not be able to provide the elaborate scaffolding that teachers provide in LCs (Bielaczyc and Collins 1999; Bielaczyc et al. 2013; Brown and Campione 1994). Additionally, peer-instructors cannot assign grades or confer credentials to motivate students to engage in challenging practices. While students might join an SLLC to work on an authentic problem, that does not necessarily mean they will be motivated to learn the community's problem-solving practices. They might instead rely on their pre-existing knowledge and skills. In other words, students who are eager to join an SLLC might not be eager to learn its practices.

Given these differences, SLLCs might work very differently from LCs, so we ask: *What instructional processes emerge in SLLCs?*

Instruction in LCs focuses on engaging learners in community practices (Bielaczyc and Collins 1999), so we answer this question by studying how peer-instructors in one SLLC attempted to teach a new professional project management practice to student innovation teams. By studying this case in depth, we can illuminate the underlying instructional processes that emerge in SLLCs.

## Background

Extracurricular, undergraduate SLLCs such as Design for America (DFA; Gerber 2014) are student clubs at colleges and universities in which student teams work on product or service design projects with real-world partner organizations. In DFA, experienced students volunteer as instructors—they scope projects, form teams, teach design skills such as prototyping and user interviewing, and implement design practices such as critique and project management techniques. Teams follow a design process to solve a real-world problem. For example, a DFA team working with a local hospital to reduce hospital-acquired infections conducted user research at the hospital and found that busy staff struggled to maintain adequate hand hygiene. The team then built, tested, and iterated upon a portable hand hygiene dispenser to promote hand hygiene compliance. To coordinate its network of 35 chapters at colleges and universities across the U.S., DFA employs 4 staff members in its national office that provide remote support (such as monthly phone calls) to peer-instructors who lead DFA studios (Easterday et al. 2018; Smirnov et al. 2017). Other examples of SLLCs in which undergraduates engage in authentic problem-solving to tackle real-world social problems include Engineers for a Sustainable World, which teaches engineering and sustainability (Dale et al. 2015) and the Roosevelt Institute Network which teaches policy analysis and advocacy (Roosevelt Institute 2016). Like DFA, these SLLCs have a small national office of adult employees and/or volunteers, but chapters are student-led.

### Benefits and challenges of learning communities

Drawing on situated and constructivist theories of learning, LCs give learners opportunities to learn by doing authentic work in real-world or simulated professional communities (Bielaczyc et al. 2013; Brown and Campione 1994). In LCs, students work together to advance their collective knowledge and skills to tackle authentic disciplinary challenges (Bielaczyc and Collins 1999; Fischer et al. 2007). Educators have created LCs for many domains, including history (Zhang et al. 2011), mathematics (Bielaczyc and Collins 1999; Zhang et al. 2011), language arts (Brown and Campione 1994; Zhang et al. 2011), natural sciences (Scardamalia and Bereiter 1994; Zhang et al. 2011; Zhang et al. 2009; Zhang and Sun 2010), technology (Hong et al. 2013), computer science (Fischer et al. 2007; Kafai et al. 2009; Zhang et al. 2017), and education (Hod and Ben-Zvi 2014).

Despite the allure of teacher-led LCs, their instructional cost limits their widespread adoption. While LCs have effectively promoted learning across the domains described above (e.g. Bielaczyc et al. 2013; Fischer et al. 2007), they require significant instructional resources. LCs place much greater orchestration demands (Dillenbourg and Jermann 2010) on teachers than lecture-based courses (Zhang et al. 2017). For example, by dividing one classroom into several project groups and having each group work on an open-ended project, LCs drastically increase teachers' uncertainty about what curriculum to prepare ahead of time, multiplying the amount of curriculum teachers must prepare to serve each group's emergent needs (Smirnov et al. 2017). As Fischer et al. (2007) note: "community-based strategies of learning are labor- and qualification-intense on the part of the universities" (p. 35), and universities are often reluctant to hire more instructors to meet these demands. Consequently, educational institutions infrequently implement LCs despite their benefits.

## The opportunity of SLLCs

SLLCs address this cost by using volunteer peer-instructors in place of teachers. This helps to explain why SLLCs have spread widely and provides an attractive way to implement LCs. However, there is little research on SLLCs, and existing LC models—based on empirical work on *teacher-led* LCs—are unlikely to apply well to SLLCs.

In teacher-led LCs, teachers extensively scaffold students' engagement in collaborative learning (Bielaczyc et al. 2013; Brown and Campione 1994). For example, in Knowledge-Building Communities (a type of LC), instructors help students to participate in scientific discourse practices by having students express their ideas using a software interface to externalize the logic underlying students' arguments (e.g., Knowledge Forum software, Zhang et al. 2011; Zhang et al. 2009; Zhang and Sun 2010). By prompting students to externalize their logic, instructors scaffold individual students' argumentation. Simultaneously, instructors scaffold the community's ability to dispute scientific claims by making logical standards explicit.

In contrast, SLLCs use undergraduate peer-instructors who have less domain expertise and pedagogical training than teachers do, so they might struggle to scaffold students. On the other hand, peer-instructors might be effective in spreading disciplinary practices because of their peer relationships within the community. Either way, these differences raise questions about how the instructional processes in SLLCs differ from those in teacher-led LCs.

Research on peer tutoring offers mixed evidence about whether students can perform instructional tasks. Furthermore, this work tells us little about peer-instruction in SLLCs because it focuses on instructional activities that are much smaller in scope and complexity than orchestrating an LC. For example, research on peer tutoring suggests that middle school students can give their peers guided feedback (Wang and Murota 2016), research on reciprocal teaching suggests students can facilitate discussions to support metacognitive reasoning in readings (Brown and Campione 1994), and children can conduct intricate scaffolding to teach their peers songs (Kullenberg and Pramling 2016). Importantly, these studies all looked at *within-task peer-instruction*, where peer tutoring occurs within individual activities, but teachers remain responsible for orchestrating the learning environment (e.g. organizing activities that give students opportunities to take on instructional tasks, designing supports for guided peer feedback, and choosing students to act as facilitators). These studies offer evidence that within-task peer-instruction *can* happen, but other work shows that it does not *always* happen (Stewart and Jordan 2017). This suggests the need for further empirical work to refine our theoretical understanding of what forms of within-task peer-instruction are possible, and under what conditions. It also underscores how little we know about other forms of peer-instruction that go beyond individual tasks to encompass orchestrating the learning environment—for example, peer-instruction in SLLCs.

## Under what conditions might students in SLLCs participate in community practices?

While SLLCs seem effective at spreading and attracting members, it is not clear how or to what extent they help members learn new practices. Even if students are motivated to take advantage of the opportunity to solve authentic problems, this does not necessarily mean that students are motivated to solve authentic problems *using the community's problem-*

*solving practices*. Because SLLCs are completely voluntary and peer-instructors cannot grant course credit or grades, students in SLLCs might not engage in the community's practices if they don't judge them useful to their social, learning, or performance goals. Instead, students might choose to stick with their pre-existing problem-solving abilities, thus limiting what they might learn. For example, imagine if students joined an extracurricular science club SLLC to build model rockets but showed little interest in using scientific argumentation practices when carrying out their projects. Such experience would not help students to develop professional scientific abilities, nor would students be likely to produce high-quality scientific claims. Novices typically struggle to self-assess their learning and performance (Dunning 2012; Yadav et al. 2011), so students might be unaware of their poor performance and unmotivated to learn new skills. This seems particularly likely when students are solving policy and design problems because these problems have no single correct solution and no clear criteria for judging success (Jonassen and Hung 2008).

## Peer-instruction in SLLCs as a diffusion process

If instructional processes in SLLCs likely differ from teacher-led LCs, what do existing theories predict about instruction in SLLCs? In teacher-led LCs, differences between teachers and students in expertise, formal authority, and age likely shape instructional interactions. But in SLLCs for undergraduates, these differences are probably smaller because peer-instructors and students might only be separated by 1 or 2 years of expertise and age (if that), and peer-instructors possess virtually no formal authority.

In this sense, learning in SLLCs may resemble peer-to-peer learning in CoPs. While CoPs studied in works like Lave and Wenger (1991) are often characterized by formal, hierarchical, master-apprentice type relationships (e.g., Lave and Wenger 1991), other CoPs are characterized by more voluntary relationships (e.g., Andriessen 2005; Brown and Duguid 1991). These relationships facilitate the spread and reinvention of practices among peers and near-peers. Organizational scholars describe this transfer of practices from one person to another in CoPs as a process of *diffusion of innovations* (Rogers 2003). Researchers have also applied diffusion of innovations theories to the study of diffusion of innovations in education (Coburn 2003), although not specifically to the spread of practices *within* a local learning environment.

Diffusion of innovations theory explains that innovations spread when a change agent influences a potential adopter's *innovation-decision process*, the process by which one decides whether to implement a new practice or tool (Rogers 2003). This can be described as an iterative process of four phases (Fig. 1):

- *knowledge* of the innovation, in which one learns about the innovation, which leads to…
- *attitude* toward the innovation, which informs a…
- *decision to adopt* (or reject) the innovation, which leads to an attempt to…
- *implement* the innovation.

Implementation of the innovation produces new knowledge and attitudes about the innovation. If implementation goes well, this increases the likelihood of continued adoption; if implementation goes poorly, this increases the likelihood of reversing the decision to adopt. Note that, for clarity, we have modified Rogers' (2003) framework, which originally referred to the second phase as persuasion, and describes the iteration of the process as the confirmation phase. Rogers used the confirmation phase to indicate that

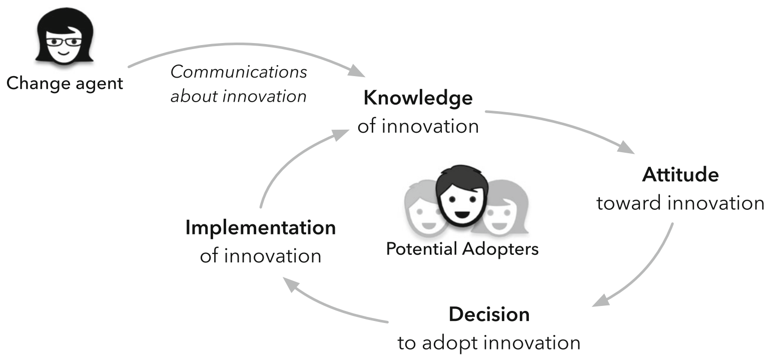


**Fig. 1** Change agents impact adopters' innovation-decisions through communication about an innovation, which gives adopters knowledge that may improve their attitudes toward the innovation, leading to an adoption decision and implementation (adapted from Rogers 2003)

people revisit their decisions over time—we represent confirmation not as a separate phase, but as the iterative traversal of four phases over time.

A change agent influences a potential adopter's innovation-decision process by communicating innovation characteristics (Fig. 1, *communications about innovation*), such as how an innovation appeals to the adopter's values. Effective change agents communicate information that will promote positive attitudes towards the innovation and enable profitable implementation. For people to develop positive attitudes towards an innovation, they must know how it is compatible with their needs, values, and pre-existing ideas, how it provides advantages over existing practices, and how to observe the results of using the innovation (Rogers 2003).

Change agents can also use social influence to inform potential adopters' knowledge of whether an innovation is compatible with their needs and values, although Rogers (2003) does not discuss this explicitly. Social influence theory predicts that group members comply with requests from peers and authorities to gain social approval, to affiliate with others, and because they expect peers and authorities to have made good choices (Cialdini and Goldstein 2004). In other words, social influence theory predicts that potential adopters weigh the social costs and benefits of adopting an innovation, and they may also defer to a trusted other to make their innovation-decision.

Additionally, to develop positive attitudes toward the innovation, people must perceive it as non-complex and easy to try out (Rogers 2003). To reap the benefits of implementing an innovation, people must know that it exists, how to implement it, and its underlying principles (Rogers 2003). Effective change agents also communicate information about their credibility as an information source (Rogers 2003).

What does Rogers' (2003) theory of diffusion of innovations suggest about instruction in SLLCs? In an SLLC, peer-instructors might act as change agents, who attempt to diffuse disciplinary practices among their peers, the potential adopters. Peer-instructors might use persuasive communication to achieve this, including rational arguments and social influence to show students how engaging in disciplinary practices will help them to reach their social, learning, and performance goals.

Peer-instructors' diffusion attempts might result in the high- or low-fidelity implementation of the original practices, but fidelity is not the ultimate measure of success. A low-fidelity implementation of a practice might be successful if people have re-invented the practice to better suit their particular context (DeBarger et al. 2013; Rogers 2003). That is, peer-instructors might make *productive adaptations* to a practice while still retaining the core design principles and intentions underlying the practice (DeBarger et al. 2013, p. 298). In fact, this is one of the things that professional instructors do to successfully create LCs in their classrooms (Zhang et al. 2011). In an SLLC, this might involve an instructor changing the frequency of a routine to align with the community's existing routines while retaining the core routine so that it retains its validity as an authentic disciplinary practice.

## Research question

SLLCs are a promising approach to implementing LCs, but existing research based on teacher-led LCs is unlikely to describe the instructional process in SLLCs. Therefore, in this study, we ask: *what instructional processes emerge when peer-instructors attempt to teach students an authentic practice in an SLLC?*

Based on our literature review of how SLLCs differ from LCs, it is unclear what instructional processes might emerge in SLLCs. It could involve scaffolding; peer-instructors might be surprisingly adept at providing extensive scaffolding to engage students in practices, as teachers do in LCs. Or, peer-instructors might struggle to scaffold students' engagement. Or perhaps understanding instruction in SLLCs requires taking a broader view where instruction involves a diffusion process. Peer-instructors might be adept at spreading practices to their peers or they might struggle in their role as change agents.

## Methods

### Study design

To answer our research question, we conducted a qualitative case study of a voluntary, undergraduate, extracurricular SLLC. We examined the instructional processes that emerged as peer-instructors attempted to teach students a specific project management practice. The insights we gained about peer-instruction in SLLCs may generalize theoretically to other SLLCs because case studies produce theoretical findings that may apply to other, theoretically similar cases (Small 2009).

### Context

We studied a Social Innovation Corps (SIC, a pseudonym) studio at a private, full-time, residential 4-year U.S. research university. SIC studios are SLLCs in which undergraduates work on collaborative, voluntary design projects to solve social challenges, such as food deserts or sexual assault on college campuses. This SIC studio was made up of the following undergraduate student members: (a) 6 peer-instructors who led the studio including forming teams and organizing studio meetings, (b) 6 team leads who led each project team and have each completed at least one previous SIC project, and (c) 21 team members who formed the 6 teams (Fig. 2). We studied the SIC studio for the 10-week long winter term. The SIC program runs each academic year and many SIC project teams work on their projects for several consecutive academic terms. We studied the studio for one term to understand studio-level instructional processes.

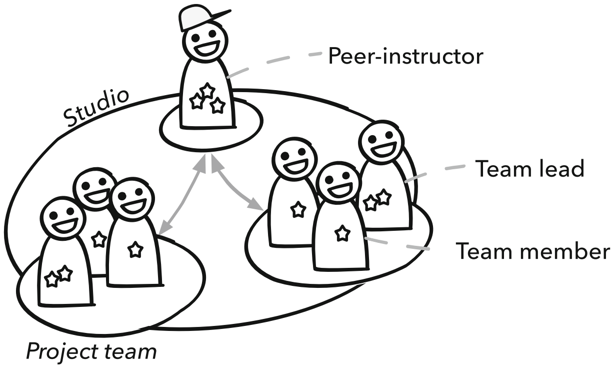


**Fig. 2** *Peer-instructors* facilitate SIC studios and *team leads* head up individual projects (source: interviews and field notes)

Peer-instructors ran weekly *Open Studios*, community-wide, 1.5-hour meetings. Project teams scheduled additional team meetings as they saw fit, usually once per week. Each team paired with one peer-instructor, with whom they met for 10 min during each Open Studio. Some peer-instructors also attended team meetings outside of Open Studio and used Slack, SIC's chosen instant messaging software, to communicate online with teams throughout the week.

## Participants

Participants included the members of the SIC studio, who ranged in: school year (first year to seniors); amount of previous design experience (none to 3 years); amount of previous leadership experience in student clubs (none to 3 years); and academic major (engineering to liberal arts to pre-professional tracks). Participants were between 18 and 23 years old. Some students knew each other from previous experiences in SIC, and some students were new to SIC but already knew some SIC members. One of the peer-instructors divided team leads and team members into 6 project teams based on their interests. Each team had one team lead and one peer-instructor assigned to mentor the team, except for 2 teams: one was continuing work on a previous project and did not have a designated team lead, and the other had 2 co-leads.

The study was reviewed by and is in compliance with our Institutional Review Board (IRB). All participants gave their consent to participate and could opt out of the study at any time. Interviewees signed informed consent forms. Peer-instructors informed all participants at the outset that researchers were monitoring Slack. The Slack interface also sent a notification to participants when researchers joined teams' conversation to collect Slack data. Participants were free to create private Slack channels (i.e., chat threads) that the researchers could not see. Researchers did not hold any authoritative role over participants (e.g. teacher/advisor) that might have influenced the power dynamic, beyond our role as researchers.

### *Peer-instructors*

An experienced team of peer-instructors facilitated the studio. The peer-instructors included 1 second year, 4 third years, and 1 fourth year. All peer-instructors were engineering students, whose majors included mechanical engineering, manufacturing, computer science, industrial engineering, and biomedical engineering. Peer-instructors had gained design experience through involvement with several design activities on campus, including previous SIC projects, a software startup, and an intensive, for-credit design research program. Peer-instructors and team leads had either applied for their position or were nominated by previous peer-instructors, who interviewed and selected candidates to fill the positions.

## Intervention

In this study, peer-instructors attempted to adapt and diffuse *StandUp,* a lightweight practice to help teams manage their project and surface problems to peer-instructors.

The *StandUp* practice is based on Agile iterative project management techniques (Sutherland 2014) currently used in software engineering and other design fields (Knapp et al. 2016). These industry techniques align closely to research principles for supporting socially shared regulation of learning (SSRL; Järvelä et al. 2015; Zhang et al. 2017) in which learners iteratively and collaboratively set goals, plan, monitor and reflect on their learning. *StandUp* follows previous research by supporting SSRL with computer-supported collaborative learning tools (e.g., Panadero and Järvelä 2015; Miller and Hadwin 2015). *StandUp* thus appeared both authentic and pedagogically useful.

In fact, peer-instructors adapted *StandUp* from a successful intervention the authors conducted in a similar project-based learning context (Rees Lewis et al. 2017). Peer-instructors had heard of our work and approached us to help apply this intervention to their context.

At the program orientation, a peer-instructor introduced *StandUp* to the project teams in a presentation. *StandUp* involved planning 2-week iterations (Fig. 3 and 4). At the beginning of the first week, teams would set goals by taking 5–10 min to discuss: "*what is your current medium-term project goal?*" and *"what are the tasks you'll need to achieve?"* At the beginning of the second week, teams monitored and reflected on their progress by asking: "*what will you do between now and the next meeting?*" and "*what are the biggest barriers to achieving your current goals?*" After discussing questions as a group, teams would post their answers on Slack (an off-the-shelf instant messaging app; Slack 2017) to a channel (i.e., a group message) including the team and peer-instructor. Team members had not previously used Slack for SIC, but some team members reported using it for other

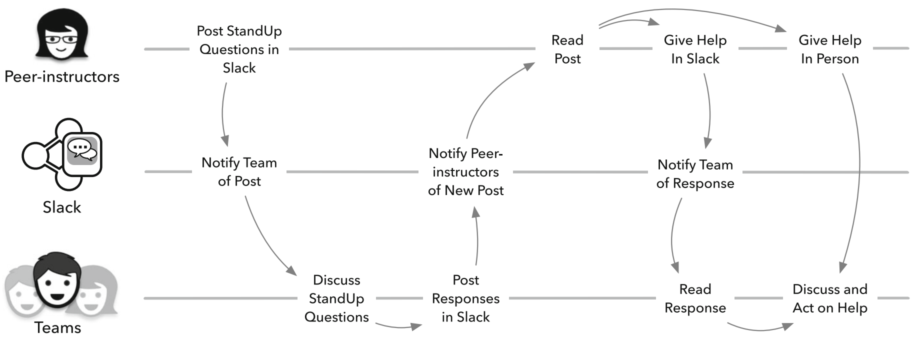


**Fig. 3** StandUp supports team planning and surfaces team challenges to peer-instructors, who can give teams help (Rees Lewis et al. 2017)

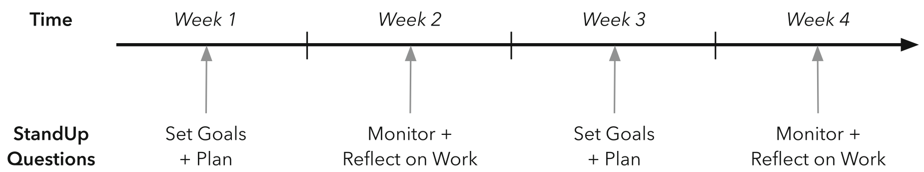


**Fig. 4** *StandUp* is a socio-technical system that supports a two-week routine in which teams answer questions that help them to set project goals and to monitor and reflect on their work (Rees Lewis et al. 2017)

student groups. Slack sent in-app and email notifications to channel members. Peer-instructors would then provide assistance in response to posts through Slack. Each team's channel was public and all students could view other teams' channels.

## Data collection

We collected interview transcripts, Slack messages, field notes, and studio artifacts (e.g. the slideshow presentation used to introduce *StandUp* during an Open Studio).

Over the course of the program, we audio recorded 17 semi-structured interviews (averaging 20–25 min) with team members, team leads, and peer-instructors on their understandings of, attitudes toward, and experiences with *StandUp*. The first author conducted all interviews in the commons area of an on-campus building where SIC students often held meetings, studied, and socialized. We sat far enough from other people not to be heard, and participants often criticized *StandUp* and their peers, which suggests they were comfortable enough with this distance to speak honestly. We conducted interviews throughout the program (weeks 2–10). We also held 1 follow-up interview with a peer-instructor 3 weeks after the end of the program. This enabled us to collect data that referred both to participants' experiences *before* and during the initial implementation, and *after* the initial implementation. We recruited interviewees by using a stratified sampling approach; we tried to interview roughly the same number of peer-instructors, team leads, and team members. To recruit participants, we requested to interview them in private messages on Slack. We told potential interviewees that our research focus was about team communication and collaboration practices, including how teams work with peer-instructors. We interviewed 5 of 6 peer-instructors, 4 of 6 team leads, and 6 of 21 team members. We interviewed most of these participants once. However, we used follow-up interviews with 1 team lead and 2 peer-instructors to ask about events that occurred after their initial interviews.

We also recorded each group's Slack conversations (633 messages). Peer-instructors and researchers told participants that Slack channels were "open," and that all studio members and the researchers could see the messages on the team channel. Messages varied widely in both frequency (many/day to a few/month) and length (1 word to many lines of text), within and across teams. The degree to which all team members contributed equally also varied between teams. We copied and pasted Slack messages and metadata (messages' content, author, and time) into a text file, and anonymized all data by replacing participant names with pseudonyms. Finally, we recorded field notes on the initial meeting between three peer-instructors and our design team, the training session between the team leads and our design team, and a final meeting with one of the peer-instructors to cross-check our initial findings. Field notes helped us to contextualize our findings and provide additional evidence about the leaders' perspectives.

To avoid leading participants, we used an interview protocol that asked general questions about participants' experiences and thoughts around *StandUp* (Appendix "Excerpts from interview protocol for team members and team leads"). Appendix "Excerpts from interview protocol for team members and team leads" reflects the kind of questions we asked team members and team leads; we asked peer-instructors the same kind of questions, but framed from their perspective. As we focused on understanding how students and peer-instructors influenced each other's decisions to implement and advocate for *StandUp*, we used probe questions such as "can you tell me more about that?" to get participants to elaborate when they began describing their decision-making. Throughout interviews, we asked participants broad questions about their projects until they mentioned *StandUp* and then asked follow-up questions. This allowed participants' own internal sense of logic to structure the interviews (Weiss 1994). When participants mentioned a conversation in Slack or another online interaction (e.g. team use of Google Docs), we asked them to show us the messages or document on a computer to aid recall and clarify responses.

### Data analysis

We did not begin this research with a specific research question, rather with sensitizing concepts (Blumer 1954) about how instruction functions in SLLCs. Sensitizing concepts are ideas that "suggest directions along which to look," in other words, they affect what researchers pay attention to in social environments (Blumer 1954, p. 7). As a product of their past experiences, most researchers cannot avoid entering the research site with a wide range of sensitizing concepts; ours included ideas of social influence, authentic design practices, and challenges of orchestrating project-based learning environments. These sensitizing concepts influence researchers' intuitions about what phenomena seem novel and consequential. In our case, as we collected and reflected on data, we noticed that students engaged in ongoing decision-making about whether to implement *StandUp*. We decided to focus our analysis on this process, and how peer-instructors influenced it because it appeared to govern the learning opportunities in the SIC studio.

Rogers' (2003) model of the innovation-decision process behind the diffusion of innovations allowed us to interpret the process we saw emerging in the data. We turned this model into an initial coding scheme using the qualitative technique of *protocol coding*, which involves drawing codes from existing theoretical models (Miles et al. 2013). Our initial codes were: communication, knowledge, attitude, decision, and implementation. As we applied these codes to the data, we saw that they did not fully describe the process we had observed. These codes captured design teams' process for deciding whether to implement *StandUp*, but not peer-instructors' process for deciding whether to advocate for *StandUp*. Using open coding, we iterated on the coding scheme to capture the full process in the data. This produced an analogous set of codes for peer-instructors (Appendix 2: "Coding scheme"; see Tables 1 and 2 for examples of coded data).

For example, we applied the code for design teams' *knowledge* of *StandUp* to an interview excerpt in which one team lead explained that they saw *StandUp* as a practice to allow peer-instructors to quickly understand their project. We gave this excerpt the *knowledge* code because it contains evidence of one design team's knowledge about *StandUp*.

For peer-instructors, the *knowledge* code applied to what peer-instructors knew about *StandUp*, but also to peer-instructors' knowledge of design teams' attitudes toward *StandUp*. For example, in an interview, one peer-instructor shared his knowledge of design teams' attitude toward *StandUp* as busy work. We gave this excerpt the *knowledge* code

**Table 1** Teams decided to trial StandUp due to social influence but reversed this decision as they developed stronger negative impressions through experience *Source* coded interviews and Slack logs

| Code | Before initial implementation | | After initial implementation | |
|---|---|---|---|---|
| | Summary | Example | Summary | Example |
| Knowledge of *StandUp* (costs/benefits, how to use) | Teams knew peer-instructors wanted them to implement *StandUp* so peer-instructors could keep track of teams<br>Teams did not know how *StandUp* might help them,<br>Teams incorrectly believed *StandUp* only involved using Slack, or sending updates | In response to a question about the usefulness of *StandUp*, team member responded, "I'm not sure. I mean, I think it's probably just for them [the peer-instructors], so that they can like make sure that we're actually getting things done." | Teams constructed additional knowledge that *StandUp* did not seem to help them with their projects | Team member shared knowledge that *StandUp* did not help the team make progress, but was "just like more work, I guess." |
| Attitude toward *StandUp* | Skeptical, unenthused | Team member said, "we're a little bit like hesitant, like as soon as we got Slack, we're a little bit hesitant." | Annoyed, dismissive, unenthused | Team lead described his and his team's negative attitudes toward *StandUp*, said, "I get a little discouraged from putting updates on it all the time. … they're not really excited when we're trying to fill out the Slack updates." |
| Decision to adopt or reject *StandUp* (includes participants justifying implicit decisions) | Teams decided to trial *StandUp* (as they understood it) because "they [peer-instructors] wanted it" | Team member said that after the peer-instructors told her team to implement *StandUp*, her team decided to try it out: "We're like, 'Okay. Yeah, we will do that on Slack.'" | Teams decided to cease implementation and/or replace *StandUp* with practices they preferred | Team lead justified an implicit decision to stop implementing *StandUp*: "And you know, it's – I don't want to tell everyone 'stop thinking, we got to go back and like set our goals at this point'." |

**Table 1** continued

| Code | Before initial implementation | | After initial implementation | |
|---|---|---|---|---|
| | Summary | Example | Summary | Example |
| Implementation of *StandUp* (or practices replacing *StandUp*) | *In a few cases*, teams engaged in collaborative planning and generated detailed posts<br>*More commonly*, team leads completed goal-setting and update posts alone (without *collaborative* planning and monitoring)<br>*And/or*, teams completed vague *StandUp* posts that provided too few project details for peer-instructors to know how to help | Team member said of *StandUp*, "I haven't done it. It's just like our team lead who's done that." | Teams implemented replacement practices that ignored many of *StandUp*'s goals<br>*Or*, teams ceased implementation without replacing | Teams stopped implementing *StandUp* regularly by the end of week 3. Teams 3, 5, and 6 stopped posting altogether, and teams 1, 2, and 4 each made one final post after this point |

because it contains evidence of one peer-instructor's knowledge about a team's attitude toward *StandUp*, which is relevant to peer-instructors' assessment of the costs and benefits of advocating for *StandUp*.

Because Rogers' (2003) model did not fully describe our data, we constructed a new model to account for students' and peer-instructors' decision processes, and the influences on those processes. We did this by coding the data, constructing data displays, and reading the data displays to synthesize findings (Miles et al. 2013).

Coding the data allowed us to empirically test if the theory we developed through open coding held across the data, and organized the evidence of the different aspects of participants' decision processes. Once the first, third, and fourth authors created the coding scheme, the first and second author independently coded 100 data segments from interviews, Slack messages, field notes, and studio artifacts (15% of total data). We achieved an agreement rating of Cohen's Kappa = .8199. We then organized the coded data by whether it referred to events that happened *before* or during the initial implementation, or events that happened *after* the initial implementation. We further condensed the data by constructing summaries that captured the key recurrent points for each code.

We then created data displays to organize the coded data in a way that made it possible to draw analytic conclusions. Our main displays were tables that show how students' and peer-instructors' decision processes changed over time. We compared students' and peer-instructors' decision processes before the initial implementation (decisions to adopt and advocate for *StandUp*), and after the initial implementation (decisions to reject and stop advocating for *StandUp*). This allowed us to capture the process over time.

**Table 2** Peer-instructors reversed their initial decision to advocate StandUp after learning implementation was costly and seemed unhelpful *Source* coded interviews, field notes, Slack logs, and 1 slide deck peer-instructors made

| Code | Before initial implementation | | After initial implementation | |
|---|---|---|---|---|
| | Summary | Example | Summary | Example |
| Knowledge of *StandUp* advocacy and utility | Peer-instructors expected *StandUp* would help them know when to give teams help<br>Peer-instructors expected *StandUp* would help teams make project progress<br>Peer-instructors knew that teams should implement *StandUp* by discussing the goal-setting or update questions every week and posting their responses on Slack | In an interview, one peer-instructor shared knowledge of the value of *StandUp*: "I understand the point of continuous check-ins because like if there's a problem, I can detect it … and I guess the problem is like the team wouldn't tell you, then there should be Stands." | Peer-instructors learned that teams saw *StandUp* as a waste of time<br>Peer-instructors learned teams' implementation often did not help (e.g. teams did not communicate many details when implementing *StandUp*) | In an interview, one peer-instructor shared knowledge of a team's reaction to *StandUp*: "they're just like 'I don't really want to do this.'" |
| Attitude toward *StandUp* advocacy and utility | Moderately enthusiastic, excited | We observed one peer-instructor say, "Actually for the mentorship program, this is going to help us a lot." | Disenchanted | In an interview, one peer-instructor reported his team's unproductive implementation gave him a negative attitude toward *StandUp*: "I was just like 'This does not help.'" |
| Decision to advocate *StandUp* or not (includes participants justifying implicit decisions) | Peer-instructors decided to advocate for *StandUp* | We observed a group of peer-instructors decide to advocate for *StandUp*. | Peer-instructors decided to stop advocating for *StandUp*<br>Some peer-instructors decided to advocate for alternative practices | In an interview, one peer-instructor reported that his team was very busy. He justified his implicit decision to stop advocating for *StandUp*, "so I don't want to add anything extra." |

**Table 2** continued

| Code | Before initial implementation | | After initial implementation | |
|---|---|---|---|---|
| | Summary | Example | Summary | Example |
| Advocacy actions (includes communication about *StandUp*) | Peer-instructors pitched *StandUp* in team lead training and in a studio meeting<br>Peer-instructors told design teams to implement *StandUp*<br>Peer-instructors posted *StandUp* questions in teams' Slack channels for the first 3 weeks of the program (Fig. 6)<br>Some peer-instructors wrote to teams in Slack to explain how peer-instructors would benefit if teams implemented *StandUp*<br>Some peer-instructors walked teams through implementing *StandUp* 1–2 times | In an interview, one peer-instructor reported: "I had to push them [the design team] to do it [implement Slack]." | Peer-instructors mostly stopped asking teams to implement *StandUp* by week 3 (Fig. 6)<br>Peer-instructors began implementing replacement practices (e.g. asking team leads for updates in person) that did not directly support teams' collaborative planning | One peer-instructor replaced *StandUp* by seeking in-person updates: "So, really what I do now, … I just saw them, just to check in. I'm like, 'Where is your project?' like 'What can I help you with?' and 'What are the updates?'" This did not require the team to engage in collaborative planning |

Finally, we used the data displays to draw analytic conclusions. By carefully scanning our data displays, we found patterns of influence that aligned with the theory we developed through open coding. Based on this, we constructed a theoretical model to summarize our findings. We argue that this model generalizes theoretically (Small 2009) to explain the interrelated social decision-making processes that constitute instruction in SLLCs.

## Results

Our case study of student leaders' attempts to engage students in the *StandUp* practice unfolded in a way that theories of LCs and diffusion of innovations could not have predicted. Based on our findings, we argue that the instructional process that emerges in SLLCs is a bi-directional diffusion process (Fig. 5). In this process, peer-instructors influence students' decisions to implement practices and students influence peer-

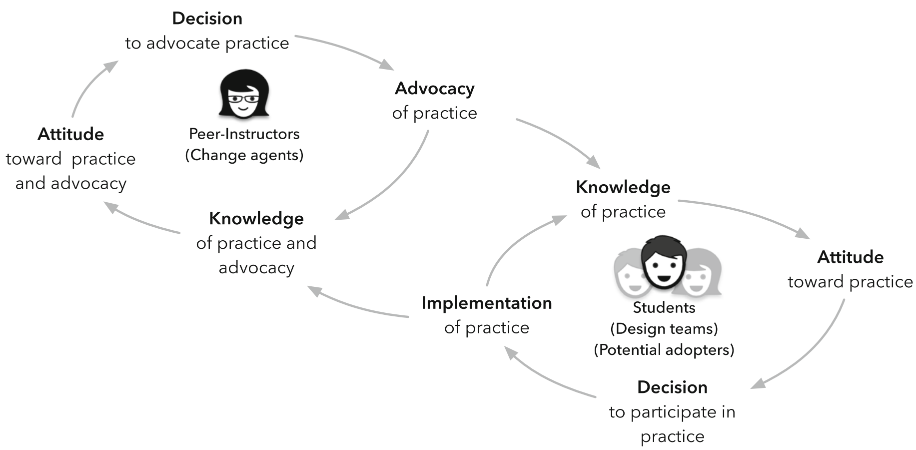


**Fig. 5** In SLLCs, the instructional process is a bi-directional diffusion process. In this process, peer-instructors and students engage in interrelated decision processes, which evolve over time to determine what practices students participate in

instructors' decisions to advocate for practices. The bi-directional diffusion model accounts for the following three findings.

First, we found that students' participation in *StandUp* hinged on whether they saw it as valuable with respect to their social, learning, and/or performance goals. We might expect that students who are motivated enough to join an SLLC would also be motivated to participate in the community's practices. However, we found that students may not see the value of participating in community practices. Particularly, they may not believe that participating in community practices will help them to reach their social, learning, and/or performance goals, and so decide not to participate. For example, students might not see how implementing a practice would help them to curry favor with peer-instructors (a social goal), to develop problem-solving skills (a learning goal), or to complete a successful project (a performance goal).

Second, we might expect that peer-instructors would be adept at encouraging their peers to participate in new practices. However, we found that the peer-instructors in our case struggled to persuade and scaffold students to participate in *StandUp*. As a result, students' attempts to implement *StandUp* were often unproductive. We found that to persuade students, peer-instructors tended to rely on social influence more than communicating and/or demonstrating how *StandUp* promotes learning and performance. For example, in an interview, one peer-instructor reported that after his team told him they did not see the value of implementing *StandUp*, he asked them, "'Okay, like can you do this for me?'" In this example, the peer-instructor created social influence by framing implementation as a question of the team's allegiance. Advocacy actions like this gave students social motivation to implement *StandUp*. But students lacked a deep understanding of how *StandUp* works, and more basically, they did not understand what learning and performance goals *StandUp* is supposed to achieve. As a result, students' attempts to implement *StandUp* tended to be unproductive; teams often provided too little detail in their *StandUp* posts for peer-instructors to give them feedback or avoided doing collaborative goal-setting and planning by delegating *StandUp* posts to the team lead.

Third, we found that students influenced peer-instructors to stop advocating for *StandUp*. If peer-instructors had training and experience, they might respond to student feedback by making productive adaptations to their instruction. However, we found a different pattern. As described above, peer-instructors relied mostly on social persuasion, with the result that students struggled to implement practices productively. Students constructed the knowledge that their implementation was not productive, and developed stronger negative attitudes toward *StandUp*. Students began to resist the practice, which the peer-instructors noticed. Peer-instructors also noticed students' implementation, which peer-instructors also judged as unproductive. But rather than adaptively improving instruction, peer-instructors tended to respond by making the community practice simpler but unproductive, or by abandoning the practice.

## Finding 1: students' decision not to implement *StandUp*

We found that students eventually chose not to implement *StandUp* because they did not see *StandUp* as valuable. Table 1 is a data display (Miles et al. 2013) that summarizes our findings about design teams' decision process, including this point, based on evidence from interviews and Slack messages. Specifically, teams did not believe that implementing *StandUp* would help them to reach their learning and performance goals of developing useful skills and completing a successful design project (Table 1: *Knowledge and Attitude, Before and After*). As we will discuss later, students initially saw how implementing *StandUp* would help them reach their social goal of pleasing peer-instructors, but this became less important over time. Based on this, students eventually decided not to implement *StandUp* (Table 1: *Decision, Before and After*). As we describe in the next section, even when teams implemented replacement practices, these practices did not achieve many of *StandUp*'s goals (Table 1: *Implementation, After*). Teams all but stopped implementing *StandUp* by the end of week 3, which we show in Fig. 6 by plotting chronologically teams' *StandUp posts* (Slack log data coded for *implementation*) and peer-instructors' *StandUp prompts* (Slack log data coded for *advocacy actions*).

Data from our interview with Kayla (a team member) illustrates this finding. Kayla described how her team decided to stop implementing *StandUp* because they did not see the value.

Kayla All of us weren't really super excited about Slack just because like it's an extra thing… that is not really necessarily going to be like it's adding anything new that we couldn't already do on email. … They [the peer-instructors] like kind of forced us on it and then we were just like, 'Let's not use this because it's not really–' Just like more work, I guess.

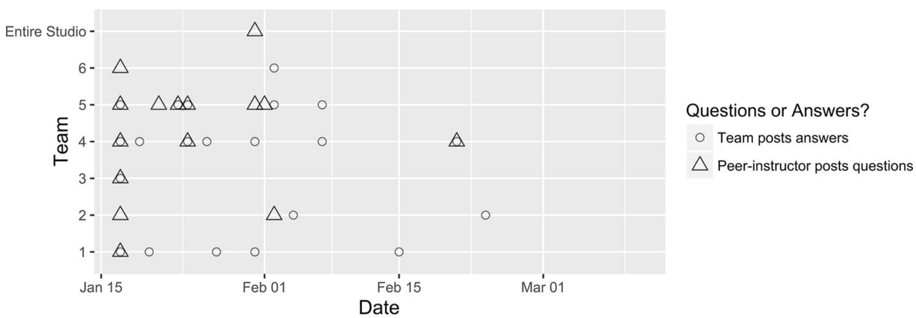


**Fig. 6** Peer-instructors mostly stopped prompting teams to answer *StandUp* questions by the beginning of the third week, and teams mostly stopped posting answers by the end of the third week (Slack logs)

Kayla's perspective about the value of Slack, the software used to implement *StandUp*, shows the difference between her account and peer-instructors' accounts of the value and process of implementing *StandUp*. Evidence from interviews and field notes suggests that peer-instructors saw *StandUp* as a practice that was more effective than email because it (a) included peer-instructors automatically in all team communications so peer-instructors could give teams support and feedback; and (b) prompted teams to engage in collaborative planning discussions to identify and overcome obstacles (Table 2: *Knowledge, Before*). In contrast, Kayla did not perceive any substantive difference between *StandUp* and email. Kayla's account illustrates how limited knowledge about the value of *StandUp* led to a negative attitude (not "super excited"), which informed the team's decision to stop implementing *StandUp*. Kayla's example shows a process we found across design teams: students' *knowledge* of *StandUp* did not include an understanding of *StandUp*'s value for teams, so teams developed negative *attitudes* and eventually made the *decision* to reject *StandUp*, which they *implemented* by the end of week 3 (Table 1 and Fig. 6).

## Finding 2: peer-instructors' influence on students

### *Peer-instructors' insufficient persuasion*

We found that peer-instructors struggled to persuade students of the value of implementing *StandUp*, which led students to implement *StandUp* in a way that students and peer-instructors found unproductive. To persuade students, peer-instructors relied on social influence, that is, telling students to implement *StandUp*, rather than communicating or demonstrating how *StandUp* promotes learning and performance (Table 2: *Advocacy Actions, Before*). This social influence motivated students to implement the practice (Table 1: *Knowledge and Decision, Before*). But students lacked a deep understanding of how *StandUp* worked, and more basically, they did not understand *StandUp*'s learning and performance benefits (Table 1: *Knowledge and Attitude, Before*). As a result, teams rarely generated detailed *StandUp* posts that communicated substantive team goals through a collaborative planning process; more commonly, team leads completed *StandUp* posts without their teammates, or teams completed vague posts with few details (Table 1: *Implementation, Before*). These implementations generally were unproductive, in that neither students nor peer-instructors perceived them to be valuable (Table 1: *Knowledge and Attitude, After*; Table 2: *Knowledge and Attitude, After*).

One example was Jack (a team lead). In an interview, Jack said his team implemented *StandUp* mostly because the peer-instructors wanted them to.

| | |
|---|---|
| Interviewer | So you said that you are still doing the updates for the—on Slack. … What is your motivation to continue to do that? |
| Jack | The way I saw it was … if [our peer-instructor] wanted to keep updated on our project, or someone else… instead of us having to update the whole time and talk to them all them, you know it'd be up there on the Slack |
| Interviewer | Yeah. But why would you want that? |
| Jack | You know, I'm not exactly sure. It was mostly I felt like they [the peer-instructors] wanted it |

Jack's example shows how design teams decided to implement *StandUp* because they knew the peer-instructors wanted them to, even though design teams did not see *StandUp* as valuable for themselves. This shows that social influence from peer-instructors persuaded teams to implement *StandUp*.

Jack's example also illustrates how design teams lacked deep understandings of *StandUp*'s potential learning and performance benefits. When Jack explained his understanding of *StandUp*'s purpose, he said nothing about *StandUp*'s main benefits: facilitating team collaboration and getting help from peer-instructors.

Finally, Jack's example shows how design teams' limited knowledge of how to implement *StandUp* led to unproductive implementation. Earlier in his interview, Jack reported that he had continued to do the posting part of *StandUp* on his own after allowing his team members to stop participating. This indicated that he believed that *StandUp* did not require team collaboration when in fact, *StandUp* required the entire team's involvement and collaboration.

### *Peer-instructors' insufficient scaffolding*

We also found scant evidence across all data sources (interviews, Slack logs, field notes, and studio artifacts) that peer-instructors provided scaffolding to support students' implementation of *StandUp*. Peer-instructors posted the *StandUp* questions on Slack for the first 3 weeks of the program (Fig. 6), but in most cases peer-instructors gave teams no guidance or support to run productive collaborative planning discussions (Table 2: *Advocacy Actions, Before*). This helps to explain why students' attempts to implement *StandUp* were unproductive (Table 1: *Implementation, Before*).

In a small number of exceptions, we found evidence that peer-instructors provided additional scaffolding. In one case, we found evidence in Slack logs that Josh (a peer-instructor) implemented *StandUp* with his team. Likewise, Molly (a peer-instructor), described in her interview how she scaffolded a design team to participate in *StandUp* by walking the team through enacting *StandUp*:

Molly The very first time we did it [the *StandUp* goal-setting routine], I thought it was helpful because I think they [the team] were—I think it guided the meeting when I did it with them and then they knew where that meeting was going, but I don't know if they realized that it was kind of helpful

Molly noticed that, with her support, the team implemented *StandUp* productively. However, Molly also noticed that the team did not see how *StandUp* was productive. We found in interviews and Slack logs that, like the other design teams, Molly's team developed dismissive attitudes about *StandUp*, and the team lead decided to stop implementing *StandUp*. As a result, the team stopped implementing *StandUp* after a few weeks.

Molly's example illustrates clearly that even when peer-instructors *did* successfully scaffold students to implement *StandUp* productively, peer-instructors did not engage in sufficient persuasion to help students see how *StandUp* was valuable.

## Finding 3: students' influence on peer-instructors

Third, we found that students exerted sufficient influence on peer-instructors that peer-instructors stopped advocating for *StandUp*. We found that as students implemented *StandUp*, they constructed knowledge that their implementation was not productive, and they developed stronger negative attitudes about *StandUp* (Table 1: *Knowledge and Attitude, After*). Students began to resist *StandUp*, and peer-instructors noticed (Table 2: *Knowledge and Attitude, After*). Peer-instructors also perceived students' implementation as unproductive (Table 2: *Knowledge and Attitude, After*). Rather than adaptively improving instruction, peer-instructors responded by implementing simpler but inauthentic practices, or by abandoning *StandUp* altogether (Fig. 6; Table 2: *Decision and Advocacy Actions, After*).

In one example, a design team implemented *StandUp* but shared too few details about their challenges for peer-instructors to help. The team also told Ryan, the peer-instructor assigned as their mentor, that they did not want to implement *StandUp*. This led Ryan to stop advocating for *StandUp*. The following excerpt of this team's Slack channel illustrates the scant details the team shared. This was one of many unproductive implementations we found in the data:

| | |
|---|---|
| Ryan | Stand<br>1. What will you do between now and the next meeting?<br>2. What are the biggest barriers to achieving your current goals? |
| Ryan | @channel: Stand is above |
| Luna | 1. Prototype unrolling kit, flip box (shapes), folding kit<br>Contact NM for user testing<br>2. Life |

In this excerpt, Ryan prompted the team to enact *StandUp* by posting the *StandUp* questions in the team's Slack channel and used the tag "@channel" to send all team members an in-app notification and an email notification. Luna (a team member) responded 11 min later with a brief message. In fact, Luna's message contained more details in response to the first question than we normally saw teams post. However, her response to the second question is vague, which would make it difficult for Ryan to offer the team help so they might overcome their barrier. It is possible that Ryan successfully interpreted Luna's response using his prior knowledge of the team and their project. However, Ryan's interview indicates this was not the case:

| | |
|---|---|
| Ryan | My team, it felt like I was like telling them to do extra stuff. … They're just like 'Do we really have to do this?' … sometimes if you like look at the [Slack] channel, they don't even answer them [the *StandUp* questions] seriously, like "what are the main challenges?", like "life". I was just like "This is not helping." And I didn't make them do it again because … it feels like it's stopping project momentum even though it's like a really little thing, super little actually |

Ryan's example shows how one design team's resistance to *StandUp*, and their unproductive implementation, influenced a peer-instructor to stop advocating for *StandUp*. In this excerpt, Ryan refers back to Luna's enactment of *StandUp*. It seems that, rather than interpreting Luna's short post using his prior knowledge of the team and their project, Ryan concluded that the team did not take *StandUp* seriously. This, in combination with the team's complaints (which Ryan reported many times throughout his interview), drove Ryan to abandon *StandUp*. This demonstrates two influences on peer-instructors' decisions about advocacy: social influence and implementation quality.

This also illustrates how peer-instructors struggled to productively adapt their instruction. Generally, it is good for instructors to make productive adaptations to their instruction. However, we found that Ryan and other peer-instructors either made *unproductive* adaptations that changed the core aspects of *StandUp* that were supposed to promote learning and performance, or simply abandoned their advocacy for *StandUp*. For example, earlier in Ryan's interview, he reported that he had begun getting updates from the team when they met in person, rather than having them implement *StandUp*. Not only did this reduce the amount of in-person time for Ryan to give the team feedback and guidance (as the team had to spend more time updating Ryan on their progress and obstacles), but it also took away the team's opportunity to learn authentic collaborative planning practices.

## Discussion

Based on our case study of student leaders' attempts to teach *StandUp* to the design teams in an SLLC, we argue that instruction in SLLCs takes the form of a bi-directional diffusion process (Fig. 5). In the bi-directional diffusion process, peer-instructors influence students' decisions to implement practices, and students influence peer-instructors' decisions to advocate for practices, which can lead peer-instructors to quickly overhaul decisions about what and how to teach. The bi-directional diffusion model furthers previous researchers' efforts to conceptualize instruction in LCs, influence and persuasion in collaborative learning, and diffusion of innovations processes. Practically, our model suggests that designers should support peer-instructors to persist in persuading students to participate in practices.

### Theoretical implications

The bi-directional diffusion model is an ontological innovation (diSessa and Cobb 2004), meaning that it conceptualizes a previously unacknowledged aspect of teaching and learning. Our model advances broader efforts by researchers to conceptualize instruction in LCs, influence and persuasion in collaborative learning, and the diffusion of innovations.

#### *Advancing the conceptualization of instruction in SLLCs*

First, the concept of a bi-directional diffusion process calls attention to aspects of instruction that prior research on LCs has not addressed. The existing literature on LCs focuses on identifying the instructional activities that teachers use to *support* students to engage in disciplinary practices. This research suggests that instructors provide different forms of *scaffolding* so that learners can engage in collaborative learning and problem-solving practices (Bielaczyc and Collins 1999; Brown and Campione 1994; Scardamalia and Bereiter 1994; Zhang et al. 2017, 2011).

Building on this work, our findings show that peer-instructors in SLLCs must support *and persuade* students to engage in disciplinary practices. Thus, instruction in SLLCs is a diffusion process. Furthermore, we found that students in SLLCs also influence instructors. Thus, the instructional diffusion process in SLLCs is bi-directional.

#### *Advancing the conceptualization of influence and persuasion in collaborative learning*

Second, the idea of peer-instruction as a bi-directional diffusion process builds on other research that is beginning to conceptualize the role of influence and persuasion in collaborative learning environments such as LCs. In contrast to previous work, which suggests the importance of influence and persuasion among students in teacher-led learning environments, this study shows how influence and persuasion are part of instruction in student-led learning environments. For example, Sullivan and Wilson (2013) found that peers used playful talk to affect their status in the group, which in turn enabled them to influence what learning opportunities the group undertook. Similarly, Jordan and McDaniel (2014) found that peers used supportive behavior to influence each other to enact strategies for managing uncertainty during problem solving. On the other hand, researchers have also observed that some students are particularly influential in collaborative learning environments, despite having normatively poor-quality ideas (Engle et al. 2014). These studies suggest that influence and persuasion among students are important factors that can both support and impede collaborative learning.

These studies emphasize the importance of influence and persuasion *among students* working as peers within teacher-led learning environments. Our bi-directional diffusion model builds on this prior work by illuminating how influence and persuasion are also highly relevant *between students and peer-instructors* in SLLCs.

We might speculate that the implications of this work extend beyond SLLCs, to teacher-led learning environments. After all, even in formal learning environments, learners have control over whether they adopt or reject the practices they learn; for example, O'Neill (2001) found variation in whether high school students in a project-based science class adopted the practice of writing in one scientific genre. And even if students appear to implement practices in the short-term, they are not guaranteed to fully adopt those practices; professional instructors might have the power (e.g. from extrinsic incentives like grades) to coerce learners to continue participating in practices *during class*, but learners may just wait until they leave the classroom to reject a practice. A diffusion model of instruction emphasizes the importance of motivating learners to engage in the specific practices we want them to learn. It is necessary, but not sufficient to make learning experiences authentic (by situating learning in a realistic task environment; e.g. Bielaczyc and Collins 1999), and developmentally appropriate (by providing scaffolding; Edelson and Reiser 2006).

Furthermore, the bi-directional diffusion model predicts that students, given sufficient social power, can influence instructors to knowingly compromise the quality of their instruction. Compared with peer-instructors, professional instructors might be more resilient to social influence from students. However, it seems unlikely that professional instructors are totally unaffected by how students react to instruction. In some cases, instructors might respond to student influence by improving learning opportunities. In other words, instructors might make productive instructional adaptations (e.g. Zhang et al. 2011). But student influence might also worsen learning opportunities. For example, if instructors' job security depends on getting positive student evaluations, then students have power to influence instructors to make instruction less challenging. As Fischer et al. (2007) have argued, student evaluations make it risky for untenured instructors to implement LCs, because students may perceive these environments as more challenging, and/or less effective than lecture-based instruction (cf. research on problem-based learning: Prince and Felder 2006; Yadav et al. 2010, 2011). Through the mechanism of student evaluations, this could threaten instructors' livelihood.

### *Advancing diffusion of innovations theory*

Finally, developing the bi-directional diffusion model required adapting diffusion of innovations theory to explain our data about instruction in an SLLC. Specifically, we modified Rogers' (2003) diffusion model by adding peer-instructors' advocacy-decision process (the process by which peer-instructors advocate for the implementation of a practice) and recognizing the bi-directional influence between students and peer-instructors.

The bi-directional diffusion model might apply more broadly, to diffusion beyond instructional situations. Change agents might engage in advocacy-decision processes, and they might adjust their decisions based on external influences, including social influence from potential adopters.

## Practical implications

The bi-directional diffusion model helps us to suggest design principles for supporting instruction in SLLCs, which align with Bielaczyc's (2006, 2013) broader effort to conceptualize and design for the social infrastructure in learning environments. Bielaczyc's Social Infrastructure design framework identifies four dimensions of social infrastructure that designers should consider. The bi-directional diffusion model helps designers to think through the second dimension, which deals with practices in the learning environment: what they are, and how students will engage in them.

We propose that, to support diffusion, designers should support peer-instructors to persuade students to participate in community practices. The bi-directionality of the diffusion process in SLLCs only makes it more important to support peer-instructors' diffusion efforts. If diffusion is initially unsuccessful, students' negative reactions will likely influence peer-instructors to stop their advocacy efforts.

The bi-directional diffusion model predicts that peer-instructors will continue advocating for a practice if they have content knowledge about the practice, the skills to teach the practice (especially persuasion skills), and motivation to advocate for the practice. First, peer-instructors need content knowledge, that is, they need to know how to implement a practice, and what utility the practice has. Second, peer-instructors need persuasion skills so they can convince their peers to adopt the practice. Third, peer-instructors need motivation, that is, they need to see how advocating the practice will help them to achieve their own goals.

Recalling that SLLCs exist within networks, which have national offices of adult employees or volunteers (e.g. Gerber 2014; Roosevelt Institute 2016; Smirnov et al. 2017; Easterday et al. 2018), designers might enlist these national offices to deliver interventions such as resources and training to local SLLC peer-instructors.

### *Mechanisms for supporting peer-instruction in SLLCs*

To promote peer-instructors' content knowledge, persuasion skills, and motivation, design-based researchers (Easterday et al. 2017) might develop interventions that target the mechanisms of selection, training, persuasion, and extrinsic rewards.

Researchers and designers might promote peer-instructors' content knowledge and persuasion skills by designing a selection system, and/or training, that promotes such knowledge and skills. Designers might also train peer-instructors to use tools that scaffold their ability to persuade students to adopt practices, rather than training peer-instructors in persuasion directly.

Researchers and designers might promote peer-instructors' motivation by designing a system for selecting, persuading, and extrinsically rewarding peer-instructors to care about supporting students' learning and performance, and to see how key domain practices promote learning and performance. This might mean peer-instructors are motivated to advocate for key domain practices in the community.

## Limitations and future work

This study is limited in that we only examined a single case of an SLLC. While findings from a single case can generalize theoretically to other cases, multiple cases are helpful for refining claims in theory-building work (Small 2009). Based on this, we suggest several directions for future work that might strategically test the bi-directional diffusion model. Future work should explore:

- the diffusion of other socio-technical systems, and practices that do not involve socio-technical supports to see how the type of practice impacts the instructional process;
- whether bi-directional diffusion is an appropriate model for instruction in other types of learning environments;
- and the design of tools and systems to support peer instruction in SLLCs.

## Conclusion

Undergraduate, extracurricular, student-led learning communities (SLLCs), offer a way to overcome the orchestration burdens of teacher-led LCs, allowing them to spread widely. But existing theories based on teacher-led LCs are insufficient for describing the instructional process of SLLCs. In this paper, we asked: what instructional processes emerge when peer-instructors attempt to teach students an authentic project management practice in an SLLC?

We showed that we can describe instructional in SLLCs as a bi-directional diffusion process. Instruction in SLLCs is a *diffusion* process because peer-instructors in SLLCs must support *and persuade* students to engage in disciplinary practices. This diffusion process is *bi-directional* because students can influence peer-instructors to cease or change their advocacy for disciplinary practices.

We found that peer-instructors struggled to persuade students of the value of *StandUp*, an authentic team-management practice, struggled to scaffold students' implementation of *StandUp*, and struggled to persist in their advocacy for *StandUp* when students struggled with and resisted implementation. Design-based researchers (Easterday et al. 2017) might develop interventions to support peer-instructors to persuade and teach their peers to adopt practices, and to persist in this advocacy. This could make SLLCs an effective and economical way to give undergraduates opportunities to develop problem-solving abilities by working on meaningful, real-world problems.

The bi-directional diffusion model provides a general model that can be applied to a broad range of learning environments (Easterday et al. 2016), with interesting implications for teaching students to apply what they learn beyond the learning environment. This model implies that students might apply strategies and knowledge in class because they know the instructor expects them to (rather than because they understand *why* these strategies and knowledge are useful). In part, this explains why students fail to apply the strategies and knowledge they seemed to have learned in class to real-world contexts. The bi-directional diffusion model suggests learning environments must focus far more on persuasion as a means to make students more likely to apply what they learn when they leave the classroom.

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## Appendix 1: Excerpts from interview protocol for team members and team leads

- Can you tell me a bit about your project and how it's been going?
- How's it been going working with your team?
- What about your studio lead – have you been talking with them much?
- How have you been communicating with your team and your studio lead?
- Thinking back to the last time you communicated with your studio lead, can you walk me through that interaction in as much detail as you can remember?
- When do you have meetings?
- What did you do during your last meeting? Can you tell me what happened in as much detail as you can remember?
- You mentioned [StandUp – *use participant's language to refer to StandUp*] – could you tell me more about that?
- Why do you use/do [StandUp]?
- Can you walk me through the last time you used/did [StandUp]?
- What do the other people in your group think about [StandUp]?
- And they said that? Or you think they feel that way because of how they act?
- Last time someone acted that way, can you tell me what they said and did as best you can remember?

## Appendix 2: Coding scheme

| Code | Full name | Applies to evidence of… |
|---|---|---|
| DT-K | Knowledge of StandUp (costs/benefits, how to use, knowledge of studio leads' credibility) | What teams knew of the benefits and costs of implementing StandUp, including social benefits and costs (why teams should use StandUp):<br>knowledge of compatibility with needs, values, and pre-existing ideas (knowledge of how StandUp aligns with my needs, values, and prior knowledge about design and teamwork)<br>knowledge of relative advantage (knowledge of how StandUp is better than what we already do)<br>knowledge of observability (knowledge of how to observe the beneficial impacts of using StandUp)<br>knowledge of non-complexity (knowledge of how StandUp is non-complex)<br>knowledge of trialability (knowledge of how we can try out StandUp without significant overhead costs)<br>knowledge of social benefits and costs of StandUp<br>ALSO, teams' knowledge of how to implement StandUp, including the processes and principles underlying how StandUp produces value.<br>ALSO, what teams knew of studio leads' credibility as a source of information about design.<br>NOT team leads' knowledge of teams attitudes (that is DT-A) |

continued

| Code | Full name | Applies to evidence of… |
|---|---|---|
| DT-A | Attitude toward StandUp | Design teams' (affective/emotional) attitude toward StandUp, including generalized or vaguely articulated judgments about StandUp<br>ALSO team leads' knowledge of team members' attitudes toward StandUp |
| DT-D | Decision to adopt Standup or to reverse adoption | Design teams' (including team members' and team leads') decisions about adopting StandUp, including their reasoning process in deciding:<br>Future tense: "I will do X"<br>OR past tense "I decided to do X" |
| DT-I | Implementation of StandUp or practices replacing StandUp | Design teams' implementation of StandUp, and what design teams communicated *to studio leads* about StandUp, including communication about design teams' attitudes toward, and knowledge of, StandUp (does not include within-team communication):<br>Past tense: "we did X," "we said something to the studio lead"<br>OR general present tense: "we do X" |
| SL-K | Knowledge of StandUp advocacy and utility | What studio leads knew of the benefits and costs of advocating StandUp, the benefits and costs to teams using StandUp, why teams think they should use StandUp, whether teams like/dislike StandUp, how teams should implement StandUp, and the processes through which StandUp produces value<br>NOT how teams *do* use StandUp (unless the data segment *also* contains knowledge about 1+ of the 6 items listed above) |
| SL-A | Attitude about StandUp advocacy and utility | Studio leads' (affective/emotional) attitude about StandUp and whether their advocacy of StandUp is going well, including generalized or vaguely articulated judgments |
| SL-D | Decision to advocate Standup or to cease advocacy | Studio leads' decisions about advocating for StandUp, including evidence about their reasoning process in deciding |
| SL-AA | Advocacy actions (includes communication about StandUp) | Actions studio leads took to advocate for StandUp:<br>Communication<br>Inexplicit communication/other advocacy (e.g. modeling or leading team in StandUp) |

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