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Supporting collaborative classroom networks through technology: An actor network theory approach to understanding social behaviours and design

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Abstract

This paper presents an implementation of Connected Spaces (CxS)—an ambient help seeking interface designed and developed for a project-based computing classroom. We use actor network theory (ANT) to provide an underutilized posthumanist lens to understand the creation of collaborative connections in this Computational Action-based implementation. Posthumanism offers an emerging and critical extension to sociocultural perspectives on understanding learning, by pushing us to decenter the human, and consider the active roles that human and non-human entities play in learning environments by actively shaping each other. We analyse how students in this class adjusted their help-seeking and collaborative habits following the introduction of CxS, a tool designed to foster (more inter-group) collaboration. ANT proposes generalized symmetry—a principle of considering human, non-human and more than human entities with equivalent and comparable agency, leading to describing phenomena as networks of actors in different evolving relationships with each other. Analysing collaborative interactions as fostered by CxS using an ANT approach supports design-based research—an iterative design revision process highlighting understandings about design as well as learning—by providing a temporal and informative lens into the relationship between actors and tools within the environment. Our key findings include a framing of technologies in classrooms as bridging *agentic gaps* between students and becoming actors engaging in different behaviours; learners enacting new agencies through technologies (for instance a more comfortable non-intrusive help seeker), and the need for voicing and teachers to connect help networks in CxS equipped classrooms.

KEYWORDS
actor network theory, collaboration, computing, design-based research, learning, posthumanist theory

Practitioner notes

What is already known about this topic

- Collaborative learning is a valuable skill and practice; opportunities to mentor others are critical in empowering minoritized learners, especially in STEM and computing disciplines.
- School norms solidify a power and expertise hierarchy between teachers and learners and fail to productively support learners in learning from each other.
- Additionally, lack of awareness about peers' knowledge is a common hindrance in students knowing who to ask for help and how.

What this paper adds

- An example of a designed interface called Connected Spaces with potential to foster more inter-student collaboration, especially outside of mandated within-group collaboration—in the form of cross-group help seeking and help giving.
- A design based research study using actor network theory highlighting the limitations of Connected Spaces in sparking notable behaviour change among students by itself but being retooled as a teacher support tool in enabling cross-group collaborations.
- Presenting conceptions of collaboration through technologies as bridging agentic gaps and acting with new agencies in performing help-seeking related actions.
- Provoking the idea of testing emerging technologies in classrooms along with sharing our analyses and reflections with the classroom as a key idea in computing education—surfacing the gap between designed intentions and the different kinds of extra social work needed in the on-ground success of different technologies.

Implications for practice and/or policy

- Designers and researchers should create and test more interfaces alongside teachers across different classrooms and contexts aimed at supporting different kinds of voluntary collaborative interactions.
- Curricula, standards and school practices should further center providing students with opportunities to engage as mentors and build communities of learning across disciplines to empower minoritized students.
- Researchers engaging in design based research should consider using more posthumanist lenses to examine educational technologies and how they affect change in learning environments.

INTRODUCTION

Bereiter (2002) emphasized the value of enculturation into knowledge building communities as integral to preparing students to be competent members of the Knowledge Age. In practice, learning collaboratively has been seen to both broaden and deepen learning experienced by peers (Marttunen & Laurinen, 2007). Cho and MacArthur (2010) describe how working with peers tends to generate non-directive feedback, which enables more complex analyses and repairs in understanding; Zhang et al. (2009) discuss the importance of collective responsibility among groups of students and also call for an increase in cross-group interactions. Giving students opportunities to mentor their peers helps them develop identities as authentic “experts” in a domain (DuBois & Karcher, 2013); this is particularly important for youth underrepresented in STEM (Maltese & Tai, 2010), in computing and engineering, as they often see these as paths “not meant for them” (Lunn et al., 2021).

Opportunities to mentor have been observed to be more useful than simply access to mentorship in affirming young minoritized learners' identities in STEM and computing (Lunn et al., 2021). We believe that these practices need to be deeply integrated into computing education itself and treated as a critical goal. Simply creating lessons for different professional computing skills is inadequate in countering systemic and social injustices conducted against underrepresented learners and practitioners (Vakil, 2018). This is particularly pressing since we also have numerous accounts of how even rich domain expertise among women and minoritized people of colour is often inadequate in supporting a deep sense of belonging in professional communities and leaving the discipline due to continued systemic and interpersonal minoritization (Rankin et al., 2021). Creating spaces and practices for letting such learners and professionals be mentors not only affirms their identity but also enables learners of dominant groups to recognize and respect expertise in minoritized students and professionals (Ryoo & Tsui, 2020).

These needs push on the rising recognition of centring social aspects of computational literacy in computing education experiences (DiSessa, 2001). As school activities design for richer collaborative learning experiences through group project work, and computing modules support better collaborative work and learning through modules to share code, and activities that support talking with each other about computing, computing educators need to create avenues and tools for students to gain mentoring opportunities, as well as create more sustainable knowledge learning communities. In this project, we narrow our focus on supporting different kinds of cross group collaborations and mentorships in a pre-existing group-based project-based computing classroom.

A key challenge in enabling cross-group collaborations lies in students having an awareness of their peers' different expertise (Ogata & Yano, 2000). Ambient interfaces have been shown to be an effective and non-intrusive means of providing this awareness (Ishii et al., 1998). In learning environments like math classrooms, ambient representations have been successfully used to support help seeking and providing assistance (Alavi & Dillenbourg, 2012); however much of this work has focused on supporting teachers to help students rather than viewing the whole class as a learning community, where students support each other.

Building on the potential benefits of unobtrusive ambient support for peers to support one another during learner-driven inquiry, we developed Connected Spaces (CxS, Kumar et al., 2017). CxS aims to support cross-group collaboration in environments like makerspaces and computing classrooms in which learners are developing their own solutions to self-identified problems, and in the process develop divergent, but potentially complementary skills (Tissenbaum et al., 2017). CxS (Figure 1) is an ambient interface that allows students to see each other's skills and serves as a means to display students' requests for help in a persistent, but unobtrusive way.

FIGURE 1 Photograph of the classroom of the study

To understand the effect a designed agent like CxS has on a classroom environment—comprising of teachers and students with pre-established roles—and its ability to change actor-relations to create a more collaborative learning community, we turned to Latour's actor-network theory (ANT—Latour, 2007).

ANT is increasingly recognized as a valuable analytic framework for educational theory and practice (Fenwick & Edwards, 2010). ANT promotes an approach to seeing an environment as a network of human and non-human entities, allowing unique insights into the kinds of actions, objects and practices, which make a social environment function and evolve in response to and alongside different designed elements. This framework—especially with its prerogative to consider non-human entities as *agentic* is uniquely suited to studying the designs of tools in learning environments and examine networked behaviours like collaborations in terms of moving across different inter-agent behaviours. Most critically, examining the technology we designed to implement in a computational action classroom acts as an analogy to the act of designing and developing technologies intended to affect local change that we are supporting students to do within this computational action driven curriculum.

Computational action (Tissenbaum et al., 2019) provides a framework for computing education which centers learners' development of their computational identities through the creation of computational solutions and innovations to authentic personal and community relevant projects. Focusing on computing as a tool to enact personally and socially relevant change moves the focus away from learning computing skills in a decontextualized way and provides a more motivating focus through the nature of socially visible and relevant work (Berland, 2016). Centring computational identities also motivates the learning of skills by providing a more robust base grounded in social and personal identities of competent computational makers and influences. The development of computational identities can be richly fostered through the social lens of computational literacy (DiSessa, 2001). Becoming a computing expert, maker or *actor* relies on being able to communicate with others belonging to similar and related communities and having the tools and understanding necessary to engage in mutually intelligible ways. This social engagement enables a more robust and sustained access to community, social support and not rooted in specific technologies or abilities, but prepares learners for a longer-term engagement with these domains.

This prerogative further motivates the necessity of tools like CxS, especially in computing classrooms. In the dynamic and rapidly changing nature of computing as a professional practice, being able to engage with peers and other experts is central in enabling students to continue pursuing computing, rather than learning a specific programming language or set of skills that can sooner or later become obsolete. CxS surfaces the peer-to-peer support aspect of computing, and encourages learners to engage with each other more, and recognize their socially distributed set of expertise and differential understandings which can benefit each other.

Thus, in this study we look at the effectiveness of using ANT to conduct design-based research (DBR—Barab & Squire, 2004) around the capabilities of CxS in collaborative learning spaces. Successful DBR relies on adjusting designs based on emergent realizations during their enactment in real-world authentic implementations of the design being studied (Hoadley, 2004). As such, ANT is a particularly useful lens for understanding a DBR implementation, as it allows the researcher to reveal the effects of a particular technological intervention within a complex social learning system, towards making necessary adjustments to the intervention to better support its intended pedagogical goals.

Furthermore, we also highlight how deploying CxS in this classroom enacts the principle of Computational Action regarding making tools that are relevant to our communities—we made CxS to be used by young students, so they learn to learn together. To properly recognize real-time adjustments, we make around deploying CxS, we explore how providing technologies to computational action-focused learners, discussing our intentions as designers with them, and surfacing the gaps between designer intentions and real-world user situations, can deepen learners' understandings of the socially relevant making aspect of computational *action*.

This work serves as an attempt to understand how CxS can better support peer-to-peer learning opportunities, particularly for those unrepresented in computing and engineering, and the plurality of forms and processes underlying divergent forms of student-driven inquiry (Halverson et al., 2018; Tissenbaum et al., 2017). Through this work, we also aim to understand how an ANT approach can reveal the efficacy of a particular design-based research intervention during its live implementation. The following questions around this project are explored in this paper:

1. How does an ANT approach help us understand how across group collaborations are approached, in particular, through Connected Spaces interfaces?
2. What changes were made to the design Connected Spaces as a result of the understanding revealed through ANT throughout the study's enactment?

We build on this analysis by thinking about extensions to computational action which lend this DBR analysis and iterations to learners as a way to more deeply engage with the process and mechanisms of their computing projects affecting change in their communities and others' lives.

BACKGROUND WORK

Collaboration in computing and making

There is significant work around supporting collaborative learning in both computing and making-based learning environments. For instance, pair programming, in which students work in pairs taking turns writing code (driving) and providing support (navigating), has been shown to increase success and retention of novices and well as improve their final products (Hanks et al., 2011). However, simply putting students together to work on a project, particularly in open-ended projects where students have a large amount of agency in how their projects are designed and built, does not ensure that students will actually work collaboratively (Tissenbaum & Slotta, 2019). In order for such collaboration to be successful, there is often a need for mutual awareness of the processes each student is undertaking, and a “metacognitive synchronization” to enable students to collaboratively work on problems (Barron, 2003).

Observing and understanding collaboration more deeply is integral to sociocultural theories and perspectives around learning. For instance, within sustained communities of practice (Wenger, 1999) , such as in project-based computing or maker spaces, as learners develop interpersonal relationships and evolving competencies, there are increased opportunities for students to organically synchronize with the work of others “over the air” (Kafai & Harel, 1991), which can enable emergent forms collaboration to occur (Halverson et al., 2018). This emergent collaboration can enable students to move between individual and collaborative goals as they advance their own designs, connecting with others as needed, and diverging to follow their own paths of interest.

The challenge with this kind of collaboration lies in the need for, in many cases, the opportunities for convergence or emergence to happen synchronously—the needs or interests of one student need to match up with the work another is doing *at the same time*. A lack of this temporal synchronization can cause students to miss opportunities to effectively connect and collaborate. These two synchronization challenges, the metacognitive and temporal, highlight the need to provide learners low-friction ways for knowing what others are doing and their respective expertise. Ogata and Yano (2000) call this understanding of others *knowledge awareness*. As much of this knowledge is often sitting just under the surface of the practices of the learning community, it is necessary to provide means for this awareness to surface in unobtrusive ways. Creating and understanding designs to surface this knowledge and the kinds of collaborative interactions they support, necessitates examining collaboration, learning, and the use of technology in ways that are deeper than simply behavioural interactions. As mentioned in the introduction, we can directly impact some of the inequities in computing spaces through the creation and sustaining of social networks, mediated by space, tools, technologies as well as participants' sociocultural backgrounds. To advance this deeper examination of social interactions, we use posthumanist perspectives (specifically ANT) to analyse the influence of Connected Spaces on collaborations.

Posthumanist perspectives on learning and collaboration

Posthumanist perspectives push us to expand how we consider the role that non-human entities play in studying different phenomena. In educational environments, these can help extend sociocultural theories described in the last section, by elevating the role that spaces and materials play in being active drivers of learning processes (Wohlwend et al., 2019). Additionally, these perspectives also encourage highlighting and centring more-than-human forces (Kuby et al., 2018) and rhythms of action (de Freitas, 2017) in the production of people, materials and learning possibilities (Peppler et al., 2019).

Latour develops ANT in his work on describing the different kinds of networks that intersect and affect each other in processes underlying creation, "settling" and "unsettling" of scientific concepts as understood and recognized across large groups of people (state, national or global societies) (Latour, 2007). This perspective complicates how different emergent interpersonal, person-to-institution and technology-to-scientist-to- institution networks lead to the production, consumption, and interpretation of scientific knowledge at numerous levels—usable across different disciplines, contexts and kinds of interactions. Woods (2020) used ANT to describe collaboration in music production workshops as embedded and enacted in the form of the music created, which acts as a legible artefact of the assemblage of peoples, practices, cultures and learning that took place. This points to a view of collaboration and the related learning as not only embedded in the interpersonal relationships, the personal, social and professional identities developed, but also embedded and exhibited in the artefacts produced by learners, and the different ways trails of collaborative actions are left visible or invisible through different modalities—a key phenomenon designed for and supported by Connected Spaces. Additionally, Fenwick and Edwards' (2010) also describe how ANT helps highlight the transformative processes underlying human-technology relationships around networked technologies in educational spaces. As people move across different ecologies with the same technology, or use different tools in the same space, the enact new *agencies*, and become different actors, which they conceptualize as the creation and performance of cyborgs.

This analysis presents new ways of considering interpersonal and social interactions—as formulated anew when different people use technologies in different contexts as *translators* (in ANT terms) of their interests and intent. This example plays a key role in how we pay attention to learners using Connected Spaces.

ANT towards computing, design, and computational action

Such analyses are particularly relevant in studying emerging educational technologies—to practice using deeper lenses to understand, criticize and design technologies and their implementations while factoring in the different actions, interactions and relationships they engage in across diverse learners.

Barad (2007) uses *material-discursive* practices as a key lens to surface the creation, practice, sustenance, and evolution of behaviours as *intra-active* entanglements. This framing describes different observed behaviours as uniquely created at the intersection of people and objects with designed, cultural, intersubjective and personal meanings embedded in the performance of the entanglement. This lens of looking at action as the creation of intersubjective agency between learners and technologies creates an analytical space that is both descriptive as well as expansive—we are able to engage in deep examination of how designers' and researchers' goals are embedded in the technologies they create, how learners perceive and re-interpret the same, and how they act alongside the technology—often in novel ways unique to their own understanding and in situ needs. This learner-technology interpretation and enaction is a key finding in our implementation of Connected Spaces, which further mirrors the work analyses surfaced by Woods (2020) as mentioned in the last section and builds on Barad's descriptions of *body-world-text* enmeshment.

In the context of developing computing understandings and identities, the different practices, and interactions that learners engage in can further reflect authentic computational practices—both in how they reflect normative professional practices, as well as expand our conception of what can comprises computational practice. ANT uniquely supports our research goals in paying attention to such plural forms of social computational participation, and how our designed technologies can surface and support different kinds of collaborative interactions.

ANT can also be used to describe and more specifically understand the goals and methods of computational action as a learning goal and design framework specifically. In computational action, we aim for learners to develop a relationship with computing where they see computing as a mediator between their personal interests and goals for social transformation. This is a specific conception of learning, which ANT uniquely supports describing and contrasting with other (computing) learning frameworks. For instance, computational participation aims to place social participation and identity construction as a mediator between learners and developing computing competence and identities.

Extending Latour's original uses of ANT to describe social conceptions of scientific knowledge production and interpretation, we find ANT a particularly productive fit for deepening our examination of the implementation of technologies in the space of design-based research, and more so in the context of a computational action classroom—where we are engaging learners in designing and creating technologies aiming for enacting social change. We as researchers design technologies and test them within institutional constraints, to cater to specific research goals, and implement and study these within the constraints imposed by broader institutional resources provided to us. This network of forces also applies to the design and implementation of technologies created by the learners for their own communities and social uses. We bring this analysis to think more deeply about how future implementations of computational action curricula can integrate an aspect of analyses for students where they can analyse how their creations, when implemented in a specific context, are often reinterpreted in novel ways, and often need an end-use stage of remediation for productive use by audiences.

METHODS

Participants and setting

This study took place in a large American urban high school, which has been recognized as one of the most ethnically diverse public high schools in the country. The curriculum was developed in close co-design with two teachers running engineering design and computing classes respectively. For the purposes of this study, we will only be looking at the computing class. This class involved twenty-four students from grades 9–12 (average age 15.8 years) and was taught as an introductory computer science class. In a pre-survey, 7 students claimed having experience and interest in writing code and engaging with computers and technology. While our analysis does not overtly leverage this demographics data, we expected the varying age groups to set the stage for even more fertile cross group collaborations that we expected CxS's design to foster. This expectation builds on the centrality of distributed and varying expertise to the design of Connected Spaces, which different ages and experiences would likely magnify.

Implementation design

We developed a curriculum that contextualized the learning in an authentic context: students across classes worked together to develop solutions for raising awareness about and cleaning up the local riverway. This structure was designed to enact the computational action framework—wherein students learn and practice computing as a means to engage in positive social change. After engaging in 2 weeks of brainstorming and design sessions, students developed teams of three-five around shared project ideas and split into sub-teams across engineering and computing portions of the project. Thus, around half of each team went to the engineering section where they built the physical elements of the developed idea, and others went to the computing section building apps connected to the same idea using App Inventor (Figure 1).

Technologies and tools

MIT app inventor

The students developed their apps using MIT's App Inventor (Patton et al., 2019), a blocks-based programming language, that allows students to build fully functional mobile applications without the need to learn complicated programming languages.

Connected spaces

The second tool, Connected Spaces (CxS), is an ambient awareness tool that was displayed on a large projection screen at the front of the class. CxS was made using a popular full-stack JavaScript based web development library called Meteor and hosted on university servers to ensure secure recording and maintaining of the data. The main ambient display of CxS, called the “main screen” across the paper, shows each student in the class, grouped by their project team, and their personally identified affinities—referred to as the skills list (Figure 2). These affinities included topics relevant to their computing projects which they are interested in talking to others about. This screen was intended to enable students to see their own interests in a concrete, public form, helping them identify with these. It also supported students knowing about their peers and being able to choose someone to approach to ask help from.

When a student required help, they would access a help portal from their browser called the “help-seeking interface” (Figure 3), and their corresponding help alert would appear on the main CxS portal (Figure 4). In the 8-week class, spanning design, brainstorming, App Inventor introduction and training, and starting project work, we collected student data about their affinities (specific computing skills they would be willing to talk to others about) in week 7 using a google form. We chose to solicit affinities and not expertise to counter the common phenomenon of imposter syndrome which would hinder students from identifying as experts, even if they were competent enough. This phenomenon has a particularly strong influence on students already minoritized and leads to further inequities in mentoring/collaboration opportunities (Rosenstein et al., 2020). Further, to surface opportunities to engage in collective computing inquiry building social computational literacy (DiSessa, 2001), rather than limiting social interactions to fixed expert-learner knowledge transfer events, we did not try to filter students' claimed affinities with any assessment of their knowledge from our perspective. This data was presented to the class only on week 8, which was the final week of their project development. While we wanted to test CxS for longer, curricular as well as project resource constraints hindered us from testing it for more time.

Data sources and analysis

For the students who provided consent, field-notes were taken by researchers well-versed in both App Inventor and CxS. Researchers acted as helpers to students as they built their projects. These field notes focused on the ways students solicited help—either by reaching out

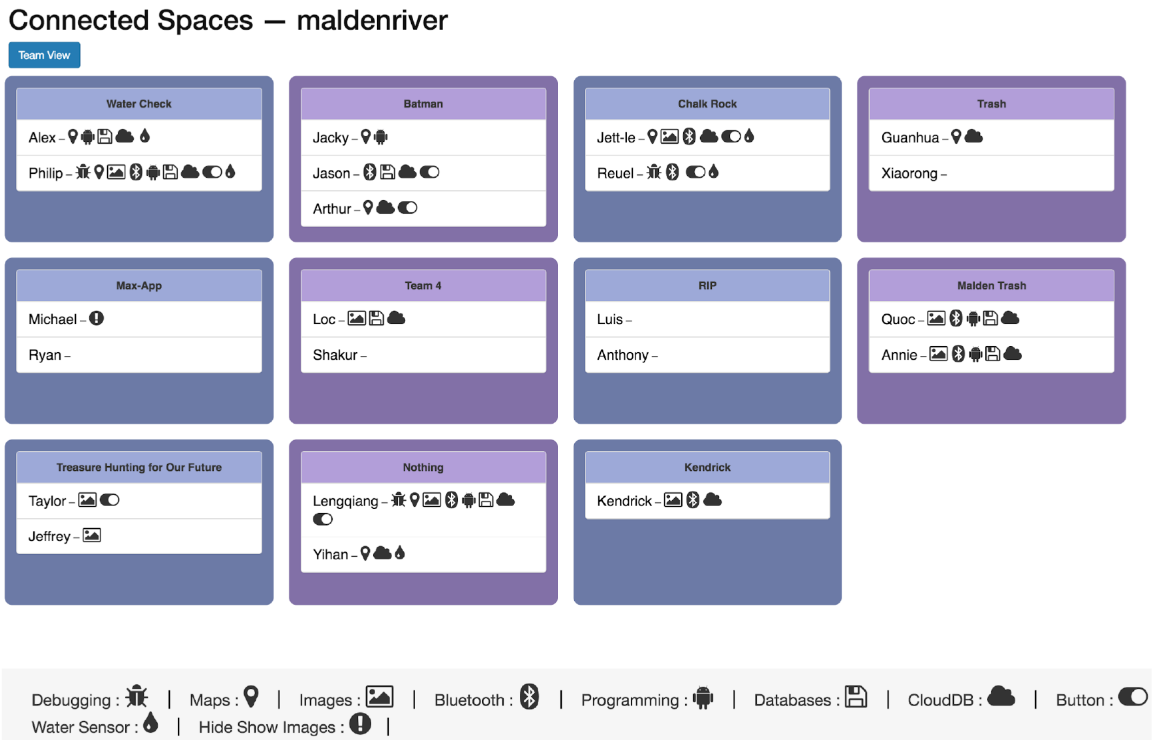

FIGURE 2 CxS's main screen as an ambient display

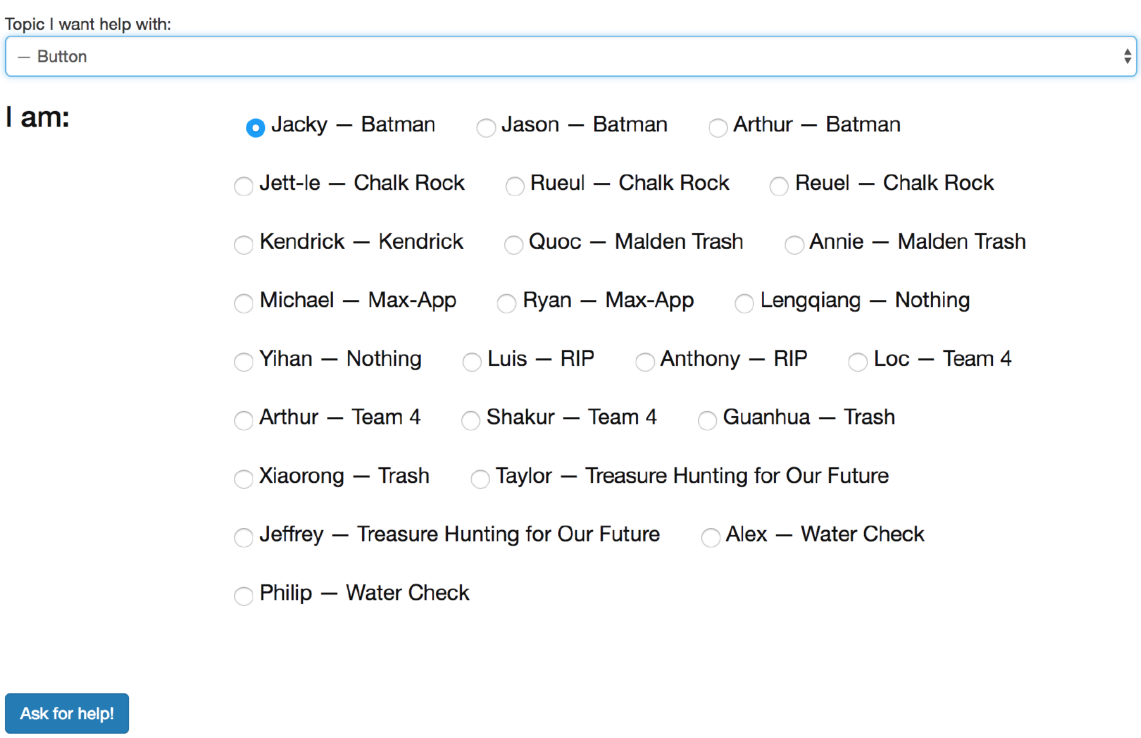

FIGURE 3 Help-seeking interface

to teachers, to each other, or interacting with the CxS interfaces (these being the only modalities we noticed). This focus was in alignment with our broad research investigation—aiming to understand how to foster richer inter-group collaborations. The findings in this paper—the

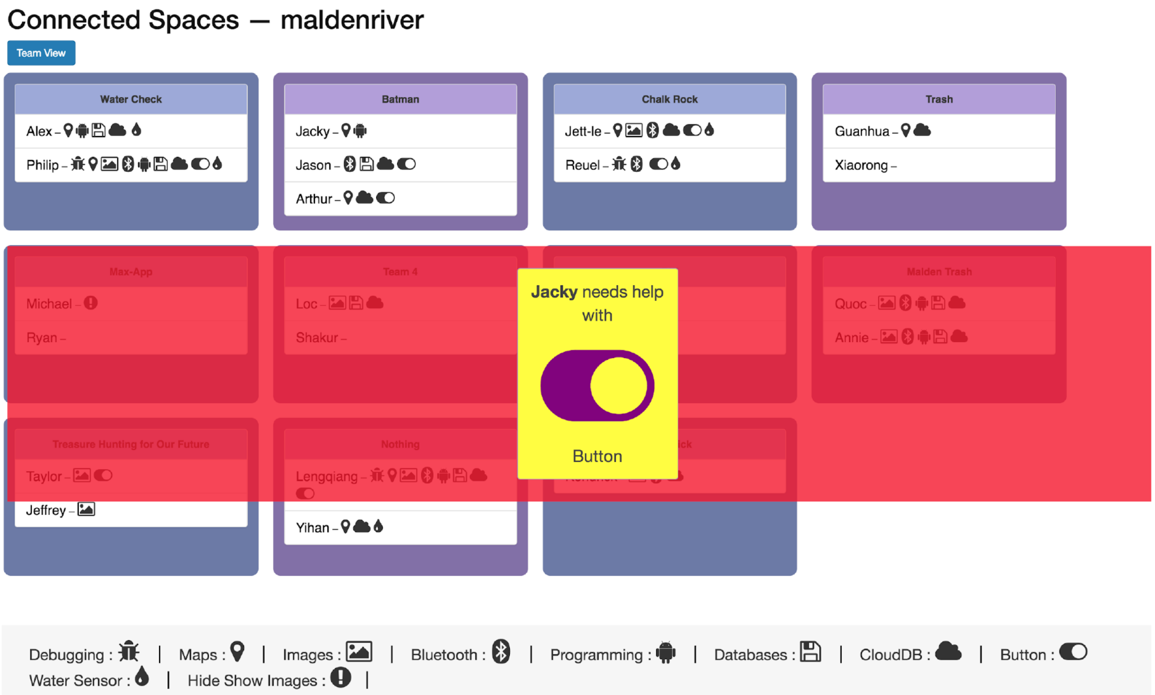

FIGURE 4 Example of a public help-call

description of the ANT in particular—is made by an exhaustive usage of all the field notes, with systematized reorganization. This involves describing the interactions as describing relationships between different entities (ie networks of actors), and surfacing design revisions we inferred as relevant for our broader research goals of fostering increased collaboration. As described in our findings, our initial actor network highlights the actors of interest as hypothesized from our theoretical background and design motivations—the CxS interfaces, teachers, and students of different groups. This is followed by describing the different collaborative interactions taking place in the classroom that we noticed and redrawing the actor network across its evolution. We do this with two goals aligned with the research questions in this work—surfacing unexpected actors as being relevant to the phenomenon of inter-group collaboration, and an example of using ANT that other educational designer-researchers can follow to develop richer descriptions of these phenomena, especially around newly introduced technologies. We couple the descriptions around using CxS with usage logs as needed, especially to fill in specifics that were missed out in field notes.

In our writing here, references to teachers includes one of the authors who was both a researcher and the main teacher for this curriculum. We present highlights of evolving cross-group interactions over the week, utilizing a selective case study method (Bassey, 1999)—where we present cases illuminating changing kinds of collaborative behaviours around CxS. Since this was the primary focus of the field notes we took, we present all our notes coupled with end of day reflections on how to revise the design of CxS in dialogue with how events unfolded in the classroom.

To cater to the analytical aspect of these interactions alongside the iterative nature of the CxS design, we group the findings per day for the first 3 days of the 5-day work week, where we reflected on the presence and usage of CxS, made adjustments to its design, and our behaviours around it. A majority of students' work was much more focused on completing their projects on day 4 and day 5 and we found a semi-stable role for CxS in the same setting, thus our findings are grouped by day spanning Days 1, 2, 3, and 4 onwards.

After describing the observations of each day's actions by the teachers, students, and Connected Spaces, we present an image, as well as tabulated descriptions of the “current” state of the classroom network (as of that day), and the following design revisions inspired by the differences between the current state of the network and the desired network. Each day highlights specific collaboration network states in the classroom around CxS, represented in the ANT diagrams and summarized in the discussion surfacing the success and shortcomings of CxS in facilitating different collaborations—this helps answer the first research question—how can ANT highlight in-situ and post-hoc perspectives on understanding collaboration as mediated by technological innovations? The tables presented in each day describing the design revisions practiced by us in response to situational observations are intended to answer the second research question—how does an ANT perspective help a DBR implementation of technology projects aimed at affecting social behaviours in educational spaces?

FINDINGS

ANT ⇄ Connected Spaces DBR implementation

For this ANT ⇄ DBR coupled analysis, we start with a reference Actor-Network (Figure 5) of the target classroom behaviours our design aimed to achieve. This provides us an easy to parse description of the target network state and expresses an easy comparison between the state of the network at any given time with what we wanted to achieve through CxS. As the study unfolded, we also recognized a need to adapt our target ANT and not be committed to a specific form—this occurred by noticing the role of unexpected relevance of different *agents* and *mediators* in the environment, and the different kinds of relationships they were able to engage in.

In this study, we began by identifying the CxS system as comprising of teachers and students as the primary actors in the network relevant to our analyses of collaborative behaviours, and the separate CxS interfaces (spread across two different links for the students and the central ambient interface), as shown in Figure 5a. In Figure 5b, we expand the category of students to include students of other groups as separate actors. This foregrounds how the activity structure (group project work) sets the stage for certain actors to see others (of the same “category”) as different. Additionally, we label the arrows with the set of actions that we expect to define/constitute those relationships.

ANT's flexibility helps make these relationships overtly visible in contrast to similar analytical frameworks like conjecture-based mapping (Sandoval, 2014) and activity theory (Engeström, 1999). Through this, we are able to examine subject-subject relationships in richer ways, by centring their perspective, and seeing the ways different actors build and change their relationships with each other dynamically, providing a more nuanced look through different subjects' lens, than an “external”, “objective” lens (Bang & Vossoughi, 2016). Leaning towards describing relationships and behaviours from an actor's point of view (ie seeing students from other groups as different actors, not just a feature of the activity structure) sets the stage for observing student actions with greater agency than other frameworks which situate the goal (object of the activity system) as the framing and anchoring piece.

Day 1—A lack of use

Day 1 saw negligible usage of the CxS system (Figure 6). As the students were in early stages of project building, we did not present the CxS help-seeking tool and only presented the main screen—a list of student names with their affinities on the class's main screen (Table 1).

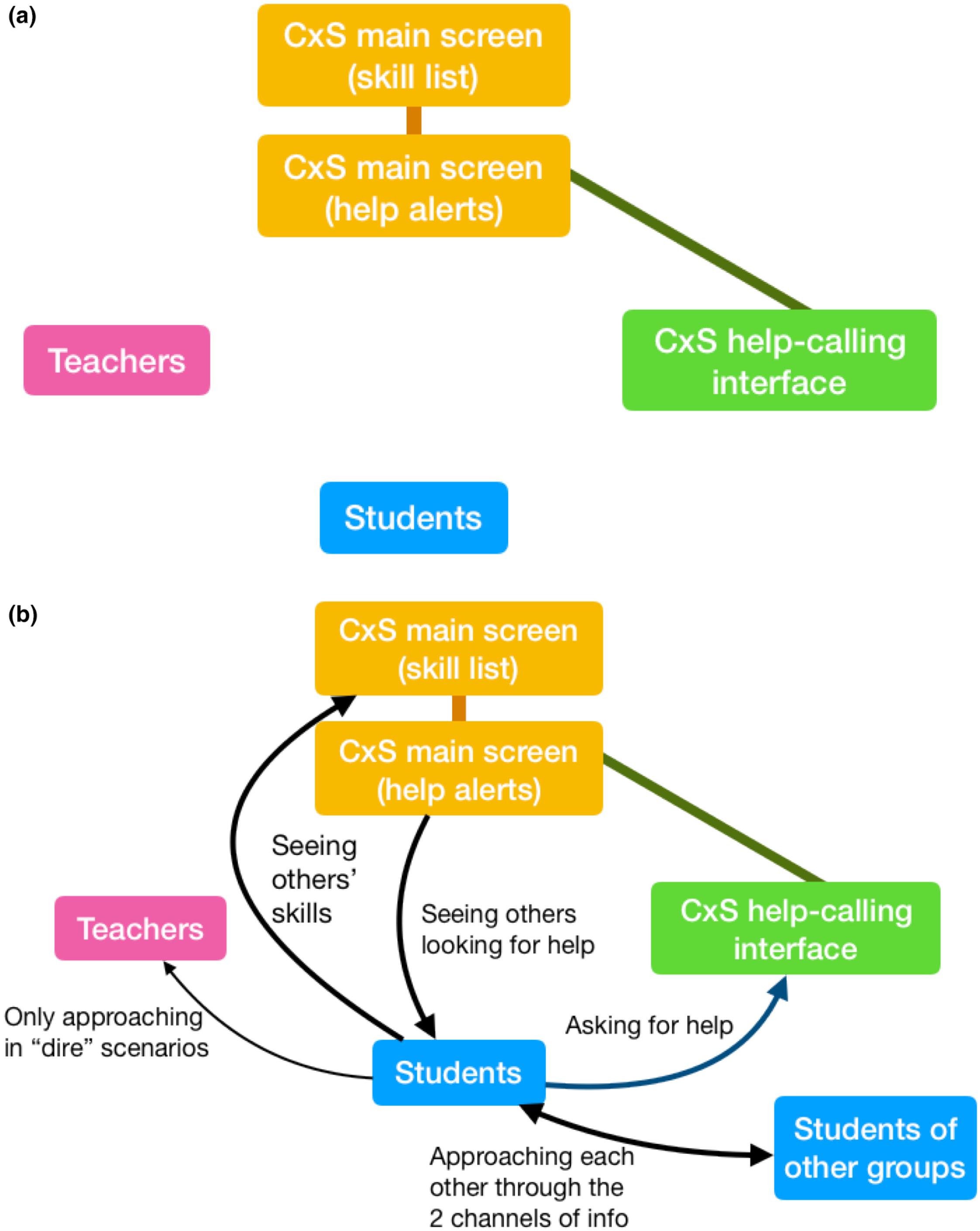

FIGURE 5 (a) Different primary actors identified as relevant to our analysis and the environment at hand. (b) Ideal actor-network relationships for collaborative learning using CxS as expected from prior theory and design goals

The network diagram also highlights which aspects of the system at hand we noticed at any point as having pertinent impact on the actions of the classroom. This aspect both highlights limited as well as evolving perspectives across different days, and the specific actors and relationships we saw as change-able by us.

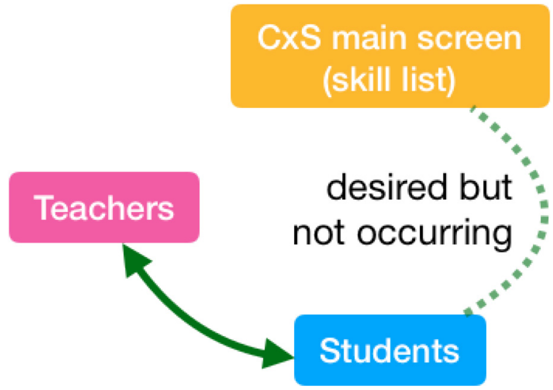

FIGURE 6 Day 1's network state—No Connected Spaces usage

TABLE 1 Day 1's observed classroom network, and associated design revisions

Network description	Design revisions
At this point, the relationships between the actors primarily only included between individuals or pairs working on their projects, and teacher(s) who they would ask help from. We saw no evidence that students looked at the skill list or tried approaching anyone besides the teachers. This lack of desired usage made us re-evaluate CxS's design to see how it can be made more accessible	The skills list had a large legend (22 affinities), with many (9 out of 22) students claiming over 4 affinities, making the display cluttered and hard to parse. These 17 affinities were at varying levels of specificity and emerged from students' own listing. After seeing the lack of usage of the CxS skill list, and the difficulty involved in parsing it, we culled the affinities down to 10, hoping to make the list more usable (change depicted in Figure 7)

Day 2—Asking for help

On Day 2, students were shown how to ask for help using the CxS web interface (see Figure 3 above). Log data showed three help requests were initiated by students almost immediately (within 20–40 s each) after showing students how to use the feature; however, these were quickly cancelled and no interactions between students were observed, indicating that students were merely trying out the system to understand how it worked (Figure 8). This trying out the system early on is an important part of becoming familiarized with the system (Table 2).

Day 3—Repeated help asking

On Day 3, we saw increased uptake of students asking for help using CxS. While the teachers were responding to in-person calls for help, two different students made requests for help through CxS. Each request was resolved in around 2 min by the teachers (us) who saw it on the alerts screen and helped the students. At one point, we noticed that a learner (Drew), had reposted their help request numerous times (4 times, totaling a span of 10 min, as confirmed by CxS logs) without raising their hand to solicit teacher attention and help more directly. We had missed noticing these calls amidst engaging with other learners, and when we finally noticed it, we asked a few other students around directly if they wanted to help Drew with integrating maps into his app. This event stood out particularly since other students would use both the CxS interface as well as raise their hands and reach out to the teachers directly. In contrast, Drew used only CxS, and avoided any direct solicitation. In the moment, we

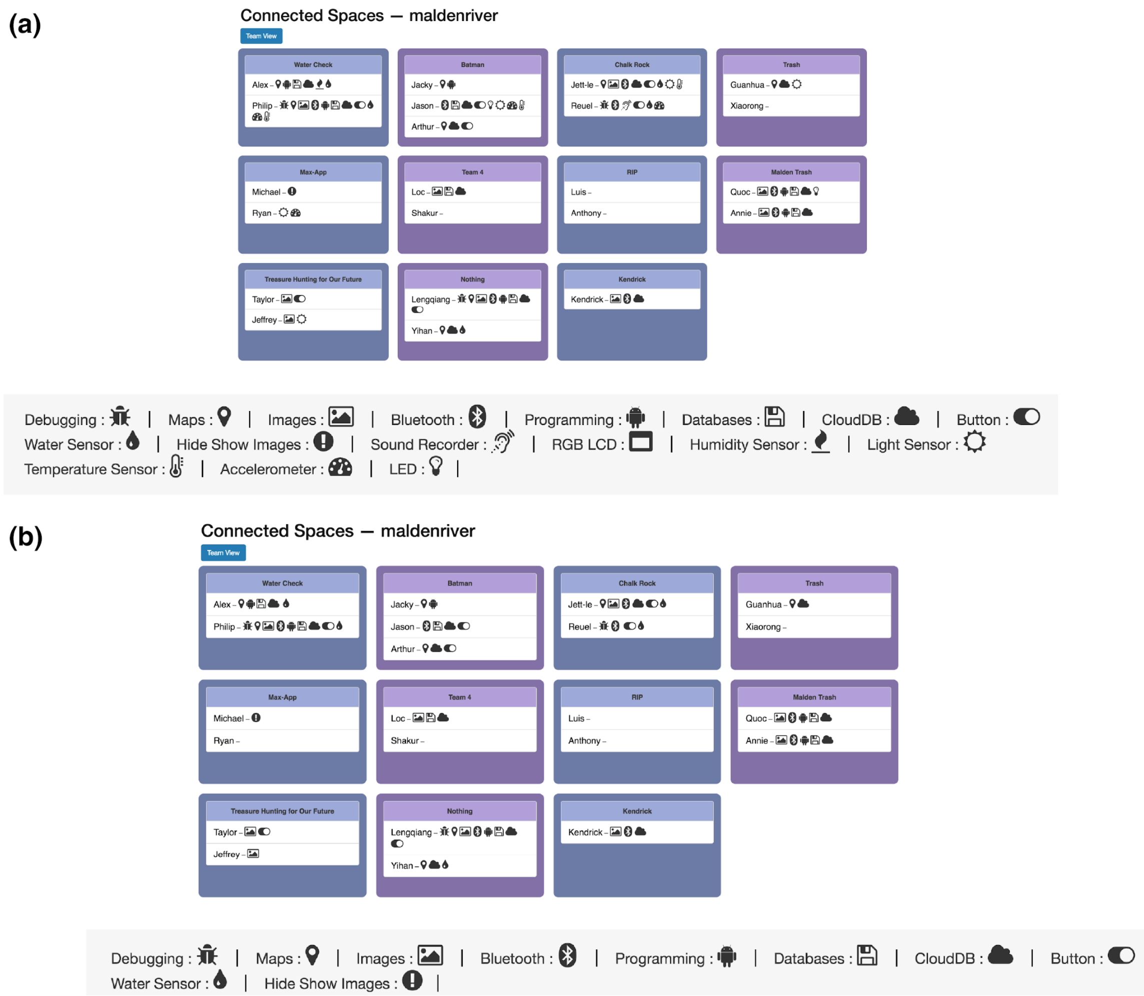

FIGURE 7 (a) First iteration of skill list screen, with 17 affinities and high information density. (b) Second version of the skill list, with 10 selected affinities for easier usage

guessed that the exclusive approach through CxS might mean Drew wanted to connect with another student and not receive teacher help. At the same time, since many other students were also soliciting help from us, we decided to solicit help offering directly from students we expected to be competent in helping Drew. Nobody seemed confident enough to solve Drew's challenge, so we helped them directly.

These help-asking instances only took place through CxS and did not involve any proactive reaching out to other students by Drew, nor did it surface other students offering help by looking up at the calls for help (Table 3).

Day 4 and onwards—The success of voicing help

On Day 4, we found greater mileage by focusing on mediating the relationship between students asking for help using CxS, and students capable of providing relevant help (through teachers' prior experience of coaching different students, coupled with information from the skill list) (Table 4). We also saw some students enthusiastically volunteering to help others, when the teacher saw a help request up on the screen, and loudly voiced it—“Who wants to help James with buttons?” A pair of students almost competed in claiming the opportunity

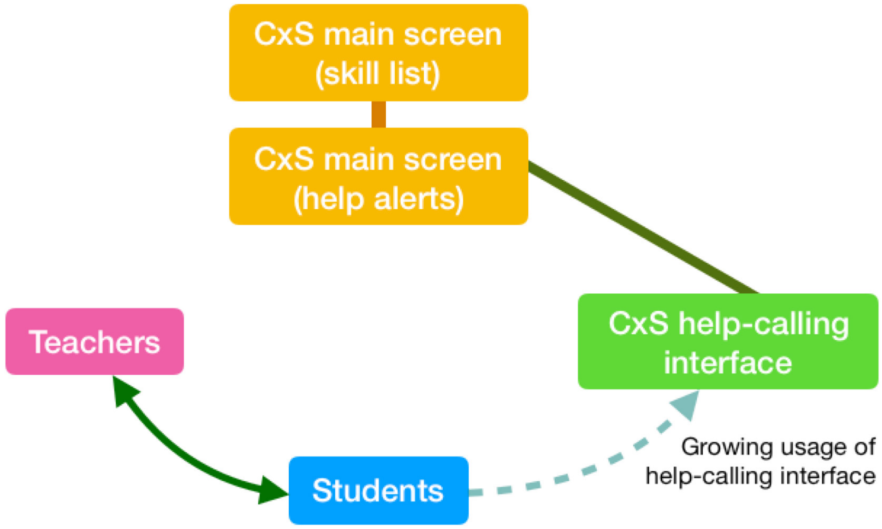

FIGURE 8 Day 2's network state—Asking for help through Connected Spaces

TABLE 2 Day 2's network and design revisions

Network description	Design revisions
Students' gradual tinkering with the help calling interface began the transition to a more collaborative space. We still did not see any usage of the skill list, especially as the teachers kept playing a proactive role in trying to help students, as well as responding to students' calls for help whenever possible	This state of classroom practices—strongly relying on teachers, willingly making calls for help but not reaching out to ask or offer help to other students—made us reconsider the likelihood of students using the skill list, given existent classroom practices and expectations of teachers being the established and accessible authority to seek and receive answers from. We redesigned the alerts to look far more “glaring”, and as teachers in the classroom, decided to try rerouting students' calls for help to their peers whenever possible by using the help alerts and skill list

TABLE 3 Day 3's network and design revisions

Network description	Design revisions
As described above, and in Figure 9, teachers became more involved users of the help alerts screen and attempted to form inter-student networks. The students' relationship with the help-calling interface appeared to have solidified, though they did not engage with any of the other parts of the CxS tool	Apart from the lacking cultural practice of attempting to help each other, it felt likely that the *main screen* aspects of the CxS tool were not being used as all students were focused on their own computer screens (depicted in Figure 9 above), and not the central display which was only looked at when any teacher would specifically call attention to it. We planned to try manually publicizing the contents of the main screen as much as possible, while trying to not distract students from their work. Since students were looking at, and using the help-calling interface, we implemented a potential helpers window beside the help-asking form as well—attempting to make it very easy to see who claimed confidence about specific topics a help-seeking student might be interested in (Figure 10)

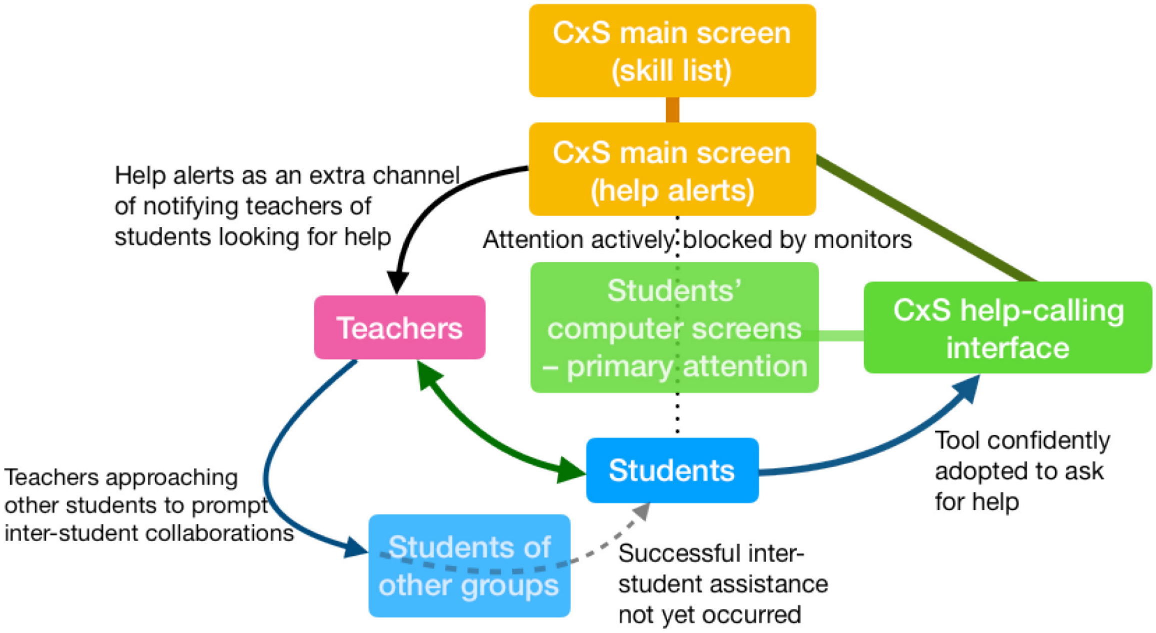

FIGURE 9 Day 3's network state—Repeated Connected Spaces asks, but no voluntary offers for help

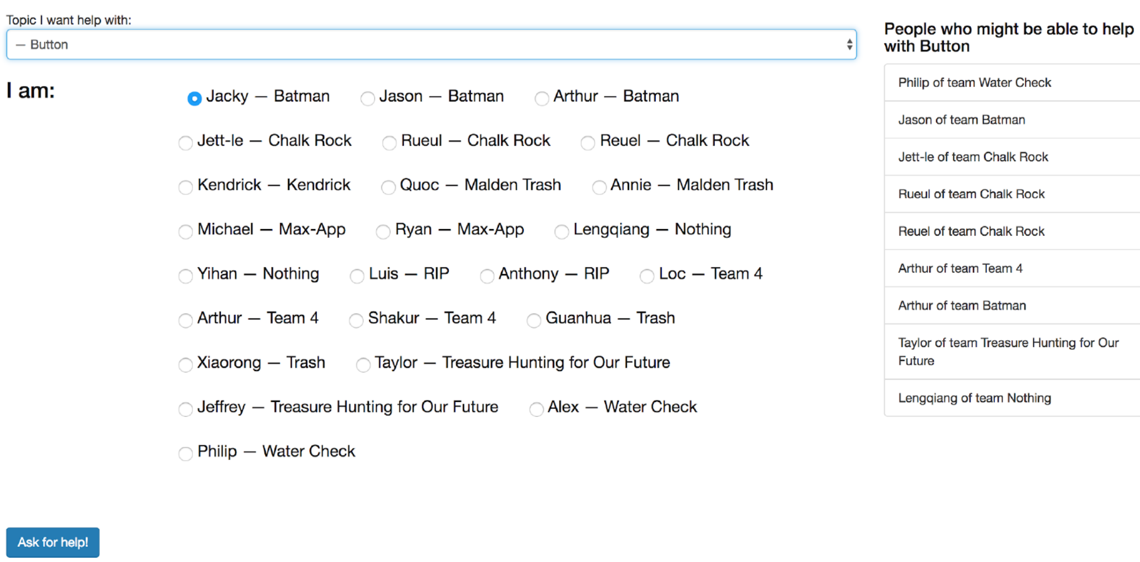

FIGURE 10 List of named helpers for chosen affinity visible on right of help-seeking interface

to help James. One of the eager students went over to the James and helped him make progress with his challenge (Figure 11).

DISCUSSION AND CONCLUSIONS

The design of Connected Spaces offers three different entry points into collaborative interactions—*offering* help (sharing interests as invitations to ask for help on the CxS Skills List on the main screen), *asking* for help (declarations of need for help in the form of help alerts on the main screen, in turn through the help-calling interface), and *helping* (inter-

TABLE 4 Day 4's network and design revisions

Network description	Design plans
Teachers were able to successfully use the skill list and help alerts for supporting students to collaborate and teach each other. Students showed no evidence of using the secondary skill list on their own displays, or proactively reaching out to each other for help (except for students with established friendships since before the class). The translation in teachers' roles as mediators of help-locators and connection makers, in contrast to the expected translation in students' roles, reflected the challenge of changing classroom behaviours in less than a week, without adequate incentives	We are planning to adapt CxS's information displays and access systems, to be oriented more towards being parsed by teachers, and design tools and practices which can help teachers reduce their role as active help-providers, while making them more effective connection makers in the classroom. We expect that after experiencing an increased frequency of receiving help from each other successfully, students might reduce their reliance on teachers and seek help from each other more directly over time

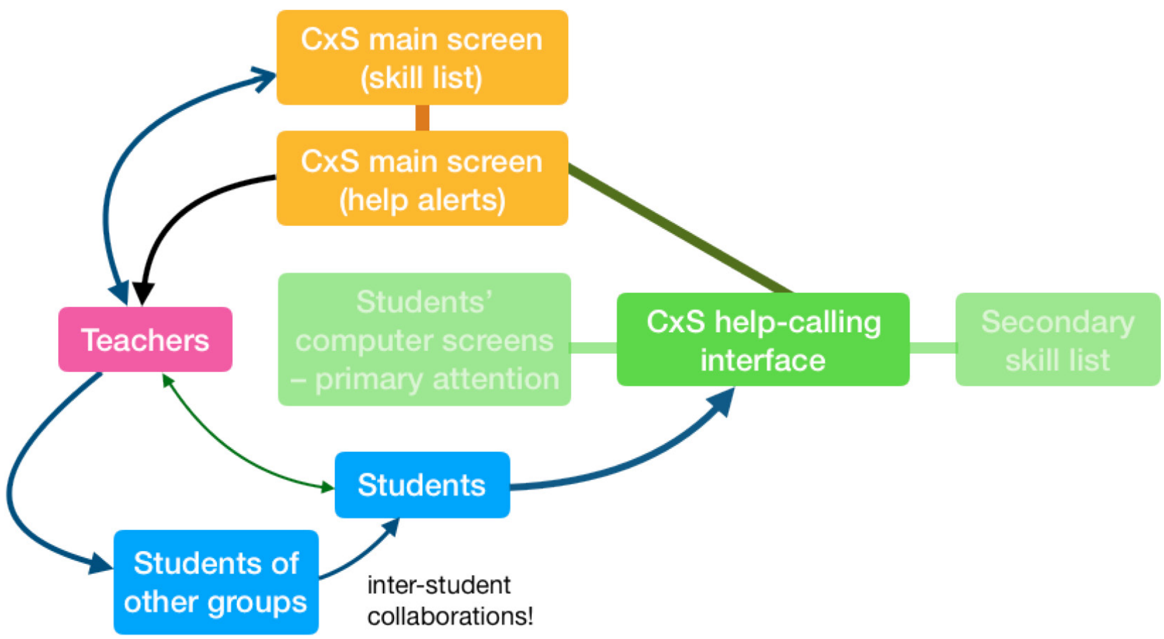

FIGURE 11 Day 4's network state—Teachers mediating inter-student collaborations through Connected Spaces

personal interactions we specifically wanted to facilitate through face to face). As depicted in our network diagrams and our observations, the act of *helping* was the one we rarely saw enacted by students through CxS itself. Following ANT's spirit of conceiving of these actions as representing different kinds of agency exhibited by actors in the network, there is a lack of actors and mediators to enable learners helping learners from other groups, without and even with CxS by itself. We call this an *agentic gap*, which was not bridged until we (as teachers) started voicing needs for help. We posit that considering learners alongside technologies as bridging agentic gaps to engage in different behaviours, provides language that uniquely opens examination of revising technologies dialogically with learners' specific proclivities, while also keeping the designer-researchers' values in mind.

On day 4, when we publicly voiced a call for help ("Who wants to help James with buttons?"), we witnessed highly enthusiastic volunteering from other students. This enthusiasm was also observed in an earlier pilot test with Connected Spaces (Authors, 2017), which led us to see the value of public opportunities to help others in CxS; it suggests that young learners are eager to help each other but need to develop both the awareness of who to help and the confidence to do so. We need to design fadable scaffolds (Puntambekar, 2022) that create conditions for students to exercise collaborative (helpful) behaviours. Classroom practices, and inadequate means for drawing students' attention to meaningful notifications seem to be major hindrances in students engaging in more collaboration.

The response to teacher *voiced solicitations for help* offers provocations needing to be investigated in further design projects aimed at facilitating such cross-group collaborative behaviour. We are working on investigating whether simply the modality of voice, even if exhibited by a passive agent like a speaker would be enough to support active responses of helping from other learners; or if it needs to be voiced by a person, or if the power-laden relationship of voicing from a teacher in this environment was key in exciting learners to offer their help. As with all other aspects of this investigation, a key question underlying all future work is how stable all or any of these behaviours are in longer term implementations.

Lastly, a key episode takes place on Day 3 where we notice how the act of asking for help is not only easily supported by the CxS help-asking interface (an agentic gap bridged by the technology itself), the act of repeatedly posting help-calls while patiently waiting for a response from anyone as conducted by Drew, reflected a new agency found alongside CxS. Before CxS, Drew would reach out for help to the teachers in the classroom, but on Day 4 and onwards, they heavily reduced raising their hand to approach teachers at all and relied a lot more on being persistent through CxS. This highlighted a transformation in Drew—a new help-seeking agency developed when equipped with CxS. This conception, as described by the Ehret et al.'s *body-world-text meshworks* (2016), is grounded in the semiotics of asking for help (Aleven et al., 2003) and Drew's subjectivity in relation to the environment and different available practices (Calarco, 2011). We can see that Drew's help seeking in the classroom is shaped in relation to their perception of teachers and their preferences regarding asking for help through active gestures like raising hands in contrast to passive moves like the “digital call for help open to response by anybody” facilitated by CxS. Conceiving of this as a novel *agency*, and not just an interpretation of CxS, helps highlight a design provocation with material benefits for equitable learning experiences—how can we think more deeply about crafting designs that respond to learners' subjectivities heavily shaped by sociocultural phenomena like racism, ableism, sexism, etc., and enable them to act in new manners, *become* new actors? The need to respond to this is corroborated by studies like Calarco's (2011) where working class students were revealed to ask for help much less than middle class students, especially in the form of direct approach to teachers. We find it valuable that Drew found some semblance of comfort in this new modality of asking for help and are further exploring different agentic gaps in asking for help that the current CxS interface did not adequately bridge, and what additional designs could better bridge the gap towards helping other learners.

Overall, we found the use of ANT in tandem with DBR to be highly valuable in helping us recognize how our designs did, or did not, facilitate the kinds of learning and collaborative behaviours we were aiming for. ANT was particularly valuable for helping us make the kinds of adjustments often advocated for by DBR during a study's enactment but are hard to capture with analysis techniques that require significant amounts of data analysis or video coding. While further post-analysis is still critical for understanding the spectrum of interactions and learning that took place, ANT can provide a surprisingly rich on-the-fly insight into the relationships between students, teachers, and various supporting technologies. We feel this work is an important step in developing methodological approaches for supporting DBR research in technology-rich learning environments.

Regarding the learning goal underlying the design of Connected Spaces, supporting students to act as mentors or helpers of their peers is a challenging endeavour, particularly when students struggle to know who to reach out to for help in timely ways. However, it is a critical step in them finding their voices and identities as authentic computing and engineering practitioners—especially in aiming to support more diverse participation in computing spaces (Ryoo & Tsui, 2020). Technologies like Connected Spaces can help reduce the friction in supporting these productive interactions. However, their efficacy is often closely tied to the needs, wants and ways of doing of the learners themselves. As such, design and implementation can be challenging to get right the first (or even second) time. It is for this reason that a DBR approach is particularly useful for the design of these systems (Slotta, 2010). Further, as shown in this study, when coupled with an ANT lens, we can parse through the multifaceted ways that students do and do not use these technologies, and how these technologies can be adapted on-the-fly to better meet students' needs. Without these adaptations, we risk developing tools that, rather than supporting students in developing an inclusive community, make them feel like the space, tools, and community are not for students like them.

Additionally, as we discussed in the start, having an early prototype of a technology to be tested by students has a promising contribution to a computational action classroom. Our real time analysis and responses, as well as DBR analysis highlights the common need of technology's ability to change social behaviour being heavily reliant on other mediators in its starting stages. While young inventors often imagine and create technologies in the awareness of and comparison with popular technologies used by them which typically take years of time and resources to be consumer friendly (including smartphones, social media, and all kinds of different applications), computing classrooms rarely surface the challenges relevant to designing, creating and deploying technologies to be used by actual people in real world contexts. We propose a supplemental layer for educational researchers implementing different emerging technologies in computing classrooms—to publicly share the design intentions with learners, and co-reflect with them how gaps in design, development and deployment can be accommodated for in a variety of ways. This makes analytical frameworks like ANT relevant for students not simply as a research tool but a way of looking at how to engage with their communities and design goals in real implementable ways.

CONFLICT OF INTEREST

There is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

The data are not publicly available due to privacy or ethical restrictions.

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