Toward Video-Conferencing Tools for Hands-On Activities in Online Teaching

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Many instructors in computing and HCI disciplines use hands-on activities for teaching and training new skills. Beyond simply teaching hands-on skills like sketching and programming, instructors also use these activities so students can acquire tacit skills. Yet, current video-conferencing technologies may not effectively support hands-on activities in online teaching contexts. To develop an understanding of the inadequacies of current video-conferencing technologies for hands-on activities, we conducted 15 interviews with university-level instructors who had quickly pivoted their use of hands-on activities to an online context during the early part of the COVID-19 pandemic. Based on our analysis, we uncovered four pedagogical goals that instructors have when using hands-on activities online and how instructors were unable to adequately address them due to the technological limitations of current video-conferencing tools. Our work provides empirical data about the challenges that many instructors experienced, and in so doing, the pedagogical goals we identify provide new requirements for video-conferencing systems to better support hands-on activities.

CCS Concepts: • **Human-centered computing → Interaction design**; **Human computer interaction (HCI)**.

Additional Key Words and Phrases: hands-on activities, remote instruction, online teaching

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1 INTRODUCTION

Online learning presents new opportunities to reach and engage learners, yet the forms and style of online teaching and learning that can take place are constrained by the affordances of remote learning technologies. For the instructor, this means that many conventional in-person classroom teaching and learning practices need to be modified [8]. Recent work uncovered how instructors and students alike need to adopt and appropriate new workarounds for supporting social and

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learning needs for most general purpose university level classes [9, 83], providing further guidance for courses that have embraced making technologies (e.g. [6]).

While these broad perspectives are useful for thinking about how online learning may be generally approached, the focus of our work is on hands-on activities in human-computer interaction (HCI) and computing disciplines. Here, students engage in learner-driven, practical and creative activities alongside their peers during class time. In HCI and computing courses, such activities are based on workplace skills [49], such as sketching and designing interfaces, building with sensors and motors, or programming microprocessors. In studio-based classes, many of these activities are collaborative, where small groups of students share in-progress and completed artefacts, as well as provide feedback to each other [52]. During such activities, instructors are responsible for facilitating and providing a supportive space; often, students get assistance from an instructor, or they learn from seeing other students' work or the feedback given to other students by an instructor.

These hands-on activities present a number of challenges, since they are often oriented around artefacts, which may be static (e.g. a sketch) or dynamic (e.g. a prototype that exhibits behaviour). This is made even more complex because some are physical (e.g. a drawing) or digital (e.g. a program), while others may exist as hybrids (e.g. a prototype driven by software). Furthermore, the class may involve a range of communication styles, where an instructor, a student, or a group, may at various times be speaking to another individual, a group, another group, or the classroom. Hands-on activities often demand being able to rapidly and smoothly move between one type of communication style to another (e.g. when an instructor discovers a mistake in the instructions given to student groups, and needs to address the entire class to clarify the intent). An instructor therefore not only facilitates the execution of the learning task itself (e.g. providing assistance or feedback), but also needs to orchestrate classroom processes to ensure success (e.g. providing resources, managing group processes).

The COVID-19 pandemic forced many university instructors to deal head-on with the limitations of online learning tools [6, 9, 33, 83]. Although literature from the field of Computer-Supported Collaborative Learning (CSCL) can offer guidance and best practices on designing and using computational supports for learning activities, few examples leverage video-conferencing technologies when it comes to hands-on activities. The problem is that researchers have not explored how to support the complex space presented by hands-on activities. Our work addresses this by studying how HCI instructors experience using online conferencing tools for online hands-on activities. Our goal is to understand what the unique pedagogical goals of hands-on activities are, and how current online learning tools could be improved to support these goals.

We interviewed 15 instructors and teaching assistants to understand how they had intended to support hands-on activities through project-based learning and related pedagogy [38, 81], and the extent to which available technologies were able to support this mode of instruction. Our analysis revealed four core pedagogical goals instructors have in running hands-on activities in their classes online: (1) being able to adapt their pedagogical interventions and activities to students' progress; (2) being able to provide guidance, feedback and critique on artefacts; (3) allowing students to learn from their peers by observing others work; and (4) allowing students to gain tacit knowledge by observing critiques and feedback. Instructors found that conventional video-conferencing tools were unable to adequately address each of these pedagogical goals, and made clear that without substantial changes in tool support, they would likely need to redefine and rethink how to achieve the same learning goals in an online context.

Our work makes three contributions. First, grounded on empirical observations, we identify a set of pedagogical goals that drive the use of hands-on activities in HCI and computing education. Second, based on these observations, we identify how conventional video-conferencing software inadequately addresses these goals in online learning contexts. Finally, based on these observations, we provide design recommendations for technology designers, showing how new solutions are necessary to address the shortcomings of existing video-conferencing tools to support teaching in HCI and computing disciplines.

1.1 Motivating Scenario

We first present a motivating scenario, to set the scene in three ways: (1) to present the nature of an example hands-on activity that instructors conducted; (2) to describe the capabilities of a video-conferencing system that was used by instructors we interviewed, and (3) to illustrate some of the problems instructors encountered in running these hands-on activities. While the specific scenario is fictional, it is synthesized from the experiences of our participants.

Ida the instructor teaches an online undergraduate course on physical computing with two hands-on activities. Like Jayathirtha et al. [33], Ida's students build an electronic textile unit by stitching and programming circuits. She is using Xoom, a fictional stereotypical video-conferencing system, to connect in real-time with her class of 41 students. Xoom provides live audio and video connection with the entire class, where Ida can share her screen (or have a student share their screen). Xoom also supports breakout rooms, where Ida can assign small groups of students to their own video-conferencing meeting.

Activity 1: Shared workbench breadboarding. Ida pairs students into breakout rooms to model a shared workbench. Students work on their own project in parallel, and can speak to another student for help. Ida drops by the breakout rooms sequentially to monitor progress. When Ida enters the breakout rooms, she has no idea whether the students are making great progress or not, and it takes time to transition from one room to the next. In some rooms, she finds them silent: students are not discussing or exchanging ideas about their projects. When a student finally asks Ida for help, she asks them to turn the camera toward their physical circuit breadboard so she can try to understand why the circuit is not working. The student holds the breadboard to the camera, but it is difficult for Ida to see details like resistors or which pins the wires are connected to. Ida needs to be very patient in instructing the student to debug the problem. All the while, she is both trying to figure out why the circuit is not working, and trying to guide the discussion such that the student can learn the process of debugging for themself. What should have been a simple two-minute exercise has now turned into 10 minutes. By the time Ida gets to the end of the period, she was unable to visit three of the groups, and discovers that one group did not even start the project because they did not know how to begin. Ida is frustrated that she did not notice that the group was having difficulties earlier.

Activity 2: Showcase. Ida's in-person showcase activity is a lively, bazaar-style event where students wander between each other's projects, trying the e-textiles, manipulating them, seeing how they work, and casually discussing the artefacts with peers. While Xoom enables breakout rooms, Ida realizes that managing the bazaar would mean manually switching students between rooms every few minutes. Instead, Ida opts for a sequential one-by-one presentation by each student in the main Xoom channel. The event is unsuccessful, students not only do not get to try out one another's projects, they feel too shy to speak aloud to everyone in the class.

The fictional scenarios illustrates how Xoom was maladapted for the classroom dynamics required in the hands-on activities, and resonate with many contemporary accounts of online teaching during the COVID-19 pandemic. Our work seeks to elucidate the underlying pedagogical goals for such hands-on activities, and provide inspiration for next generation video-conferencing tools to support these activities.

2 RELATED WORK

Within educational research in computing, prior work has emphasized the importance of engaging and promoting motivation for student learning [50, 56, 65] with making and creating playing a pivotal role. Guzdial argues that, "A student who takes an introductory computer science course wants to make something. Even if the student doesn't want to become a professional software developer, they want to create software, to design something digital." [27]. Although working with others was a common learning objective in computing courses [57], research on collaboration in computer science learning is generally scarce [17]. That said, research on pair programming where teams of two learners take turns designing, coding, testing, and debugging on one work station is a prominent example of collaborative learning in the computing education space that leverages a technique used in professional software development [22, 43, 53, 76, 80].

From the perspectives of computer-supported collaborative learning (CSCL) and social constructivist theories, learning is essentially a social activity where knowledge is constructed through interaction with others [78]. Thus, programming pairs learn from one another by accessing each other's Zone of Proximal Development. CSCL uses technology to mediate and facilitate interaction between learners. For example, in group programming, a predefined sequence of steps (i.e., scripts) provided by the platform guides the collaboration [76]. Other scholars examining programming with robotics employ intelligent tutoring systems to form groups and support collaboration through generative feedback from learner models [62].

In contrast to designing instructional scaffolds such as scripts to encourage participation, open-ended collaborations, such as reaching out to peers spontaneously, can generate emergent collaborations (for example, in maker spaces; [30]) and can provide a means to support student agency, acknowledge expertise, and embolden creativity [17].

While the research on online learning and collaboration has started to identify the opportunities for design interventions, it is not yet clear what specific educational goals should be prioritized when designing new platforms to properly support online hands-on activities with video-conferencing tools. Additionally, education technology designers could draw from prior work on remote collaboration technologies that has addressed some of the challenges instructors and students are currently facing.

2.1 Online Learning Before and During the COVID-19 Pandemic

In the context of skill acquisition and practice, numerous online communities exist to support learning. For instance, Stack Overflow is an important online learning resource used by developers to overcome technical difficulties through methods such as question and answer threaded discussions [4]. Other online communities such as Instructables and DIY.org offer similar learning benefits for makers [46]. More formally organized ways to provide education online have appeared in the form of Massive Open Online Courses (MOOCs) offering academic courses online to large groups of remote students from all over the world [48]. However, while MOOCs succeed in bringing the formal structures of in-person instructional approaches to an online format, this form of online learning still suffers from a number of drawbacks comparing to traditional education forms. One of the main limitations is the lack of support for a direct communication between students and instructors. The direct face-to-face instructor-student communication is critical for learning activities, particularly those that involve artefact creation. Consequently, MOOCs organized around the use or creation of various artefacts are rare [29].

High-speed internet has encouraged educators to leverage common video-conferencing platforms for educational use, allowing them to organize smaller-scale formal remote learning classes with a direct line of communication between the students and the instructors [40]. Subsequent research has ascertained that real-time audio-visual communication increased students' feeling of social presence, immersion, and learning performance [28, 82].

The COVID-19 pandemic further accelerated the transfer from in-person classes to video-conferencing-based groups [9]. However, the research on video-conferencing-based learning is scarce, and it is still unclear how learning processes are enacted and supported in such settings.

Several recent studies have documented the impact of the COVID-19 pandemic on students and educators, demonstrating that the instructors' workload increased as a result of transferring their teaching activities online [6, 9]. In particular, the instructors experienced the growing need to engage and interact with the students more and in many different ways [6, 9]. Teachers usually created more quizzes and other online materials, and engaged in more direct conversations with students [9], as well as provided more pedagogical support in the form of progress check-in meetings and targeted sessions [6]. However, despite increased pedagogical efforts, students experienced a reduction in the quality of education, and satisfaction [6, 83], primarily due to the lack of sense of community and flexible opportunities for engagement with peers and instructors [83].

Thus, preliminary recommendations by researchers include incorporation of opportunities for peer work and collaboration, providing affordances for social communication signals, increasing diversity of possible interactions [9], and enabling both synchronous and asynchronous communication opportunities [21, 83]. In contrast to this prior work, we focus on documenting how the rapid switch to online teaching affected hands-on pedagogical activities that produce physical and digital artefacts, typical of UI/UX, coding, physical computing, fabrication, and other making activities. These types of activities have unique characteristics as they are based on close collaboration and guidance from the instructor, and they also provide opportunities for peer learning. Questions that arise during hands-on activities are responded to in-situ [33, 54]. Such "just-in-time" opportunities for peer-to-peer and teacher-student guidance are made possible by the deliberate design of modern classroom as a setting for scaffolded social support [45]. Yet, little is known about how these interpersonal dynamics are translated to the context of online hands-on activities using video-conferencing platforms.

2.2 Online Learning Environments with Media-Rich Communication Tools

Considerable efforts have explored how to integrate various types of media—text, audio, and video, into computer-supported learning experiences [19]. Previous research in education has found that using a rich combination of media in presentation and communication of the learning processes can enhance students' attitudes [36, 64], communication [58], and learning outcomes [5]. This is likely due to the high media richness afforded by multimedia communication in student and instructor interactions [5].

Media richness is a concept that reflects the capacity of the communication medium to facilitate shared meaning and understanding of a message [10]. The communication richness of a media depends on its feedback capability, language variety, support for personal focus, and the amount of communication and social cues that are possible to convey. Thus, media richness gradually decreases from face-to-face communication to video, voice, images, and finally to text and numbers being the leanest form of media [61, 75]. While the increasing capabilities of online communication technologies generally led to increasingly rich media, they still lag behind collocated face-to-face communication in many ways. It is particularly hard to support various feedback modes and communication cues in online communication using body language, gestures, position in space, gaze, and other forms of non-verbal behaviors [24].

The more complex and difficult the task, the richer the media that supports the communication between the collaborators is required [68]. In this respect, online education can arguably benefit from the richest possible medium of communication as it involves many complex group and individual activities, tasks, and modalities of interactions between students, instructors, and the learning content [2]. Media richness becomes particularly important in the context of hands-on activities, where non-verbal interactions and thus the ability to communicate using non-verbal cues is important. However, to date, media richness in the context of education has been primarily explored in terms of designing multimedia instructions and tutorials [68] and online education forums [5, 58]. To the best of our knowledge, it has not yet been explored whether video-conferencing tools can sufficiently provide rich media for facilitating online hands-on activities.

2.3 Supporting Group Activities in Remote Video Communication Platforms

Designing platforms for group-based hands-on activities requires implementation of ways to support both group and individual interactions, which depend on the ability of the collaborators to be aware of each others' actions and work [25]. The Computer Supported Cooperative Work (CSCW) community has contributed a multitude of video communication platforms to support remote hands-on tasks [18, 42, 72, 73, 84], and explored the ability of collaborative groupware to support users' mutual awareness [12, 25, 26]. Although not directly related to hands-on activities in online teaching, this body of work had provided important insights on some of the challenges instructors and students may typically experience in an online context.

2.3.1 Supporting mutual awareness in remote group-based activities. A major challenge in the context of remote group work is the reduced mutual awareness of the participants. Mutual awareness refers to the up-to-the-moment understanding of another person's interactions with the shared workspace, and is a critical contributor to the success of remote collaborative activities [24, 25]. One of the main challenges for establishing mutual awareness in collaborative group work stems from the inability of the users to properly and independently observe each other's work [23]. During typical in-person class activities, seeing others' work is known to provide students with the opportunity to discuss and learn from each other [31, 74]. Thus, it is important to provide mechanisms to enable peer observation. In this line of work, some have explored the use of regular webcam snapshots of collaborators' workspaces which led to an increase in collaborators' mutual awareness [13, 20, 51]. Instructors also need to be able to observe what their students are doing in order to monitor their progress. Previous work has proposed a wide range of technological solutions, including the use of multiple displays [47] and more unconventional solutions, such as interactive lamps that display students' work status [1], and ambient displays that aggregate individuals' work into one shared view [44]. While Lui and colleagues' work [44] focused on co-located situations, similar approaches are even more critical in remote learning scenarios, where there are fewer ways and opportunities for instructors to synchronously monitor students' work.

In the context of group-based activities, the awareness of remote collaborators is often reduced due to their inability to effectively coordinate verbally using only a single audio-channel that lacks spatial audio cues typically present in co-located settings [55, 77]. When using traditional video-conferencing technologies, students and instructors' verbal interactions are broadcasted which limits the ability to have side conversations. Some have tried to address this by allowing individual users to lean towards a unit representing a collaborator's position in a 4-way round table meeting [63], or by defining and supporting different types of communication channels [70]. Contemporary tools based on shared virtual environments are now becoming increasingly popular and address more effectively and easily challenges related to group interactions. Platforms such as gather.town[1] and Mozilla Hubs[2] allow users, who are represented by an avatar, to move in an

[1] https://gather.town
[2] https://hubs.mozilla.com

virtual environment and communicate with people who are in their proximity as these platform support spatial audio.

While multiple solutions for increasing mutual awareness exist, during the COVID-19 pandemic, the effective rapid deployment of video conferencing tools in education depended on institutions and individuals to quickly adopt the technology and properly adapt it to their needs. Such tools are widely accessible and require only minor adjustments for deployment on a wide-scale. However, the ways in which mass video-conferencing platforms can support mutual awareness in online education, particularly for hands-on activities, has not yet been explored.

2.3.2 Supporting joint visualization and manipulation of objects. Beyond effective communication, the success of remote hands-on activities often depends on the ability of both instructors and students to work collaboratively on shared artefacts. Joint visualization and manipulation of artifacts is challenging during remote collaboration as instructors and students often do not share the same physical space and have no physical access to artefacts. Early CSCW literature explored the use of video-conferencing platforms to support remote work. Englebart's "Mother of All Demos" illustrates a remote working context with a shared digital document as early as 1968. Systems such as ClearBoard [32], VideoDraw [72], and VideoWhiteboard [71] explored shared digital workspaces. In the mid-1990s, researchers began focusing on shared physical workspaces. Drawing over video environment (DOVE) [59] considers a video-captured environment where the remote expert can draw on a video. This video is transmitted back to the learner and provides a method for the instructor to gesture remotely and thus guide a student performing a hands-on activity. Remote gestures such as cursor pointer and drawing over a static video feed allow the use of deixis which makes communication easier. Several researchers explored various camera/projector approaches, taking this thinking to the logical extreme with shared tables (e.g. [37, 69, 84]) and upright digital whiteboards (e.g. [3, 15, 69]).

The research had also proposed a variety of creative mixed reality approaches to tackle the problem of joint work on remote artifacts [14]. A series of works by Billinghurst et al. (e.g. [7, 39, 41, 60]) consider how head mounted displays can enable remote assistance in a physical workspace. OptoBridge is a canonical example of this type of approach that uses augmented reality (AR) [67]. Here, an instructor remotely guides a student in the manipulation of a Michelson interferometer. The hands of the instructor are represented over the workspace in AR to the student wearing an AR head mounted display. Here too, the system allows the instructor to provide live feedback and guidance to students by using remote gestures.

CSCW researchers have proposed multiple methods, approaches, and modalities to enable successful remote collaboration. However, as with the case of mutual awareness support, it becomes increasingly evident that most of the proposed solutions require large scale investments in designing and deploying new types of complex hardware and software systems. The need to quickly switch to online education due to the COVID-19 pandemic made the restructuring of instructors' teaching very challenging, resulting in the adaptation of several common video-conferencing platforms. In this context, researchers need to better understand how both students and instructors participate in hands-on activities via these platforms. Our study aims to be a step in this direction. Specifically, we study how instructors use current video-conferencing tools for enabling and managing hands-on activities, and what educational goals and needs arise from this form of online education.

3 INTERVIEW STUDY

While prior work provides considerable context for online learning from the perspective of remote collaboration, as well as the challenges of social interaction and general distance learning during the pandemic, our specific interest in hands-on activities presents nuances that have yet to be addressed. For instance, while a lot of interaction in hands-on activities focuses around physical or digital artefacts, it also implicates complex classroom dynamics that have not yet been addressed in prior literature.

We designed an interview study to learn about instructors' challenges in achieving their pedagogical goals while conducting hands-on activities online. We were interested in how they communicated with, interacted with, and gave feedback to students, and the difficulties they faced with adapting the hands-on components of their course in line with the pedagogical goals that emerged in an online format with the tools they had access to. Our analysis revealed that instructors had several pedagogical goals in running hands-on activities, and that the current generation of video-conferencing tools did not adequately address these goals. As a consequence, instructors and students encountered significant disruption.

3.1 Participants

During the COVID-19 pandemic of 2020, many universities stopped in-person classes and moved to online teaching part way through the semester. We took this opportunity to recruit instructors and teaching assistants affected by the sudden switch to online classes and interviewed them between May and June of 2020—shortly after participants' courses were completed for the semester. We expected that participants with this very recent experience within such a critical moment would have memorable and impactful stories to tell about both the in-person and online hands-on components of their courses.

We recruited fifteen participants (8 instructors; 7 teaching assistants) through personal contacts, social media, and Discord servers. To participate in the study, a participant had to be an instructor (the teaching lead), or a teaching assistant (the assistant to the instructor) only if they had led or facilitated the hands-on components of a course. Additionally, we required that participants' courses had hands-on components such as projects, assignments, or in-class activities which had not been previously taught online before the pandemic. All participants reported using hands-on activities in their university-level computer science and engineering courses. They were from nine different universities in North America, Europe and Asia. Participants' teaching experience ranged from less than one year to more than 10 years and class sizes varied between 12 to 500 students. Table 1 summarizes information about the participants and their courses. Here, we differentiate between instructors and TAs; however, in our subsequent discussion, we refer to all classroom facilitators as instructors during the hands-on activity. Participants received a $20 gift card remuneration.

3.2 Methods

We conducted semi-structured interviews over Skype or Google Meet, audio recording each session. Interviews lasted from 26 to 55 minutes (average: 41 min). We asked for an overview of their course, the nature of the hands-on activities and their pedagogical goals, how the switch to online affected the hands-on component of the course, the challenges they encountered in delivering the hands-on activities online, how technology limitations affected this delivery, and how they gave feedback to students.

3.3 Analysis

The audio recordings were transcribed using IBM Watson Speech-to-Text service and corrected by the authors. To analyze the data collected and identify instructors' pedagogical goals and challenges, we used open, axial, and selective coding. The two lead authors collaboratively analyzed the first interview transcript using open coding to identify the challenges instructors encountered trying to support their pedagogical goals, and to describe instructors interactions. These codes were descriptive and included participants' strategies, challenges, goals, hands-on activities, and

Table 1. Participants and their courses

	Course Topic	Course Level	Class Size	Instructor (I) or TA	Years of Teaching Experience
P1	Data Visualization	UG	130	I	>10
P2	Data Visualization	UG	25	TA	2
P3	Data Visualization	UG & G	60	TA	2
P4	User Interface Development	UG & G	260	I	3
P5	Information Visualization	UG	50	I	Decline to state
P6	Mobile Robotics	G	15	TA	1
P7	Introduction to Programming	UG	500	I	>10
P8	Electronics	UG	20-30	TA	<1
P9	Product Development	UG & G	40	I	5-7
P10	Interactive Media	UG	16	I	>10
P11	Web and Mobile Development	UG	65	TA	1
P12	Virtual Reality	UG & G	12	TA	3
P13	Electronics	UG	96	I	>10
P14	Data Visualization	UG	25	I	>10
	Introduction to Programming	UG	100	I	>10
P15	Electronics	UG	24	TA	3

interactions with students. Then, the same authors discussed and used axial coding to group codes into tentative categories in order to identify relationships and similarities between them. For example, these categories included "instructor awareness", "artefact sharing", and "student-instructor interaction". The two authors individually open coded half of the transcripts, and held frequent meetings to discuss codes and iteratively perform axial coding. Finally, during the selective coding stage, these codes coalesced as a set of challenges faced by instructors while trying to support their pedagogical goals, and explained the outcomes of the hands-on activities. Following these efforts, all co-authors met together to identify a final set of findings which led to the four pedagogical goals presented in Section 4.

3.4 Summary of participants' practices

Teaching Platform. The most common video-conferencing platform used by the participants was Zoom[3], and two participants used an online educational system provided by their university. Eight participants used Zoom breakout rooms to facilitate group activities or for the instructor to discuss individually with a student while others stayed in the main conferencing session. Our instructors typically shared a video feed of themselves during lectures and activities but told us that most of their students did not reciprocate (similar to [83]). In addition to Zoom, three participants used Discord[4] to communicate with students through audio and text channels. All of these platforms allow users to share their screen, and thirteen participants reported using this feature during hands-on activities to share digital artefacts. Additionally, nine participants had students use this feature to share digital artefacts to the instructor or other students. For example, when needing help with programming, a student would use screen sharing so that the instructor could see their code and provide assistance.

Hands-on Activities. Participants described 21 unique hands-on activities that were part of their courses. Fifteen of these activities involved creating or modification of artefacts in small groups (e.g. sketching data visualizations, building simple electronics, prototyping user interfaces, prototyping virtual reality experiences). In these cases, the artefacts themselves were the focal point of the activities. Two activities were discussion-based activities, while the remaining four were activities

[3]https://zoom.us
[4]https://discord.com

completed individually by the students. Table 2 presents a summary of nine typical hands-on activities conducted by the participants.

Artefacts. The hands-on activities involved several kinds of artefacts. Physical artefacts consisted of electronic components (micro-controllers, circuitry, sensors and microprocessors), an autonomous mobile robot, two-dimensional objects (paper sketches and posters) and three-dimensional objects. Digital artefacts included software applications, computer code and computer code output (web/mobile app, VR experience and data visualization). In the activities involving electronic components and a mobile robot (both physical artefacts), digital artefacts were also part of the activities as students needed to write computer code to make the physical artefacts functional.

We grouped the 17 activities (six were excluded as previously mentioned) into nine types of hands-on activities that vary across a number of dimensions: (i) involvement of the instructor; (ii) creation vs. modification of an artefact; (iii) the type of artefact (e.g. digital vs. physical); (iv) size of the group; (v) stages/sequences/styles of engagement between students. Table 2 briefly presents examples of how each type of activity was executed by a participant along with the type of artefact involved in the activity.

4 FINDINGS: PEDAGOGICAL GOALS OF RUNNING HANDS-ON ACTIVITIES

Hands-on activities have a number of clear educational goals where the intention is to learn, practice or gain skill or knowledge of the task at hand. As illustrated in Table 2, these skills frequently involve creating or modifying an artefact in particular ways, and the purpose of running them in small group situations is to allow students to learn from one another through discussion [34]. Beyond these knowledge-level goals, many instructors use hands-on activities to enact a teaching model beyond the "sage on the stage" approach.

To this end, our analysis revealed four pedagogical goals (PGs) instructors had in running hands-on activities in their classes that relate to classroom dynamics, and how they expected students to learn from one another:

> **PG1:** The activity should allow students to receive pedagogical interventions adapted to their progress during the activity.
> **PG2:** The activity should allow students to receive guidance, feedback or critique on artefacts as they are being created or modified.
> **PG3:** The activity should allow students to learn from their peers by observing others' work.
> **PG4:** The activity should allow students to gain tacit knowledge by observing critiques of and feedback given to others' work.

We discuss each of these pedagogical goals in turn, and then describe how instructors encountered difficulties achieving these goals given contemporary video-conferencing tools.

4.1 Adapting pedagogical interventions and activities to students' progress (PG1)

A common rationale for running hands-on activities in classes is to provide feedback "on-demand" to students that need it. Instructors reported needing the ability to monitor students' activity and progress as they engage in hands-on activities in order to adapt and tailor their interventions. In conventional face-to-face contexts, all the instructors reported engaging in casual "walk-arounds", where they would wander around a room, looking at both the student's activity as well as their body language to assess whether students are not progressing well, or are stuck. Some students also use these "walk-arounds" to opportunistically pull the instructor aside to ask a question in a less public way.

In our sample, eight instructors could not easily monitor activities of small groups or individual students. Rather than being able to move through the interstitial physical spaces to indicate

Table 2. Examples of nine in-person hands-on activities described by the participants

Type of activity	**In-person example of this type of activity**	**Group and class size**
Physical Visualization	Students build a physical data visualization with objects such as playdough, Lego blocks, construction paper, and paper clips brought in by the instructor. (e.g. [P2])	Group size: 3-4 students Class size: 25 students
Sketching	In groups, students individually sketch data visualizations on paper while discussing and brainstorming with other students. Selected sketches may be shared to the whole class. (e.g. [P5])	Group size: 3-4 students Class size: 50 students
Showcase	For their final project, groups of students build a storyboard and the last class of the semester is dedicated to a showcase. Each group places their storyboards on tables or walls as a collection. Students walk around the classroom at their own pace and direction to look at the storyboards. Students leave sticky note comments including critique and questions on the storyboards. Students are free to discuss the storyboards with others as they do the activity. (e.g. [P4])	Group size: 3-4 students Class size: 260 students
Virtual Reality Experience	Development of a virtual reality experience with a haptic component for a museum exhibition. At the end of the course, students showcase their project to the class and collaborators from the museum by letting them try the experience firsthand. (e.g. [P12])	Group size: 2 students Class size: 12 students
Programming of Data Visualizations	Students complete weekly lab assignments where they implement data visualizations using the Javascript programming language and the D3 library. (e.g. [P3])	Group size: 2-3 students Class size: 60 students
Programming of Web and Mobile Applications	Semester long project where students develop a web and mobile application. Weekly meetings with the instructors and the TAs allow students to get help and feedback on their progress. At the end of the semester, the TAs conduct a live evaluation of the applications in front of each team of students. (e.g. [P11])	Group size: 5-6 students Class size: 65 students
Programming of an Autonomous Mobile Robot	Students program a mobile robot to autonomously complete a scavenger hunt in the hallways of the university. The robots have to find QR codes representing letters and place the letter in the correct order to form a word. Students use algorithms taught in the theory portion of the course and implement them in their robot. The last class of the semester is dedicated to the scavenger hunt where everyone gathers to watch the robots. (e.g. [P6])	Group size: 3 students Class size: 15 students
Programming and Building Microcontrollers	Students complete weekly assignments where they have to program microcontrollers to communicate with external circuitry such as sensors and breadboards. A weekly lab period is allocated for students to complete the activity and to ask questions and get help from the TA and peers. (e.g. [P15])	Group size: 3-4 students Class size: 24 students
Rapid Product Development	The entire class of students was tasked to build a technology product to improve the quality of life of people with Parkinson's disease. Smaller teams of students were assigned different parts of the overall system. Some have to build circuits and sensors and others had to program software-based parts of the system. The end goal of this class project is to demo to external collaborators (patient with Parkinson's disease, primary caregiver, doctors, and neuroscientists). (e.g. [P9])	Group size: 3-4 students Class size: 40 students

"availability", instructors would "barge into" a student's space. For instance, the Zoom platform allows the instructor to put students into virtual breakout rooms so they can engage in small group activities (shared audio channel and ability to share digital workspaces); however, for the instructor to monitor an activity, she needs to enter each breakout room one by one. This action takes time, is disruptive to the group dynamic, and does not allow the instructor to maintain any overall awareness of all groups. P2 describes this contrast: "In person, even if I'm not right there and talking with each of the groups, I can see whether they're working or not, or how well they're working. [I can do this easily] by looking around the room." P14 describes this problem of not being able to easily monitor the class: "I don't know if they're actually doing the activity... At the end of the term, I could look at the documents they posted, so we could see if people participated."

When using breakout rooms, instructors resorted entering each breakout room in sequence, which could be quite onerous. P5 recalls: "I didn't realize that when I did two person breakout rooms, it would mean that I would have to visit twenty rooms. I didn't realize how much overhead it would take to switch between groups." One consequence of this is that some rooms simply would not get attended to in the time allocated for the activity. Another consequence of this was that urgent issues from students might not get attended to until quite late. P2 recalls such an incident: "When I got into this one group they said, 'Oh thank god you're here! We've been stuck on this thing for so long!' and I had no idea they were stuck." P2 described the experience of entering each room in turn as being a bit of a lottery: "Sometimes I would go in, and I would find that everyone's in a nice discussion, they're kind of like creating ideas and stuff," whereas other times, groups would be sitting in silence with cameras off, and clearly not working together effectively.

Instructors reported relying on this "looking around" particularly during the execution of hands-on activities. Without the normal noise and background chatter of hands-on activities (i.e. feedthrough [11]) it is difficult for the instructor to gauge whether students understand the activity. While the breakout rooms allow teams to operate in isolation of one another, they also prevented instructors from being able to effectively monitor what was happening in each room.

4.2 Providing guidance, feedback and critique on student artefacts (PG2)

Instructors offer direct "in-the-moment" assistance to students or small student groups as they engage with the activities. In our data, we observed both activities where the guidance or feedback was given directly to a group in a private breakout room, and activities where critique or feedback was provided in front of the entire class (e.g. as feedback following a presentation). This feedback is typically focused on the artefact that the group is producing. For instance, instructors will give guidance when students are unsure of how to proceed with the task, or give feedback/critique when the instructor wants the students to concentrate on a particular aspect of the design approach.

As reported by all the instructors, they need to be able to understand the state of the artefact to be able to give effective feedback. This was difficult with both physical and digital artefacts. For example, in describing an episode where she needed to help a group debug a physical circuit, P10 remarks: "Sometimes [students] hold [a circuit] up to the camera, but it's rather difficult to be able to see where the wires go and [...] the details." This creates an additional burden if the student's camera view does not match what the instructor wants to see, or when the instructor needs to direct the student to reorient the object or reposition the camera.

For multi-part artefacts spanning several devices, problems were even more pronounced. Most screen-sharing tools only allow a single "view" to be seen at once, which means that only one part of the artefact can be seen at a time. P9 describes an instance where helping a student to debug an application was extremely cumbersome with screen-sharing: "When we were looking at hardware, there [was] a lot of back and forth. 'Hey can you show me you know your code', [and then] 'Can you show me the serial debugger', and then 'Can you show me the hardware.' I think we were able to [...] go back and forth with screen sharing." This toggling back and forth creates new work on the part of students who now need to manage views of multiple artefacts simultaneously.

Verbal remote control. To manipulate physical objects that only exist in the student's workspace, seven instructors resorted to "verbal remote control" through the camera, where instructors give fine-grained verbal instructions to the student on how to perform certain manipulations or to move the artefact so the instructor can better visualize it. P13 contrasts this with his in-person teaching experiences: "[When in person] I can just touch that wire and pull it out and put it back into a different spot. So, [online] I have to walk them through the process." P10 needed to resort to this strategy when navigating code—just to understand what the artefact was doing: "They would be scrolling through the program and I would say 'Go up a little bit. You know that line right there? What is that doing?"'

Additional auxiliary materials. In some cases, two instructors resorted to asking students to prepare additional materials to explain the artefact. For instance, P3 recognized this problem for an activity involving web-based visualizations. Rather than asking students to share narrated videos of the action, she asked students to submit screenshots of their visualizations in various states. Reflecting on her solution, P3 suggests that it was inadequate, because it "failed to capture the dynamic behaviour of the web visualization."

4.3 Allowing students to learn from their peers by observing others' work (PG3)

Students need to be able to engage with each other's work: many hands-on activities are designed to explicitly have students engage with one another's work (e.g. "showcase"), while other activities are intended for students to freely move from one another's desks to inspect and casually see others' work as they themselves work. The problem with current technologies is that the instructor singularly controls the students' attention: the instructor shares her slides, or her screen; alternately, the instructor gives "screen sharing" control to another person in the joint call. Only in rare instances did instructors report using additional external tools like a shared document editor in conjunction with the teleconferencing software.

In "showcase" style activities, instructors would split the classroom such that students could wander around to see one another's projects. These activities are explicitly designed so students can engage with one another. However, in the online context, this was not as easily accomplished. P10 describes having to scale down a "showcase" event, commenting that the excitement was missing. Similarly, P2 describes trying to run a showcase of physical visualizations—charts and graphs made with physical materials—that students created at home. While she could still do a "show-and-tell" with students using their webcams to show their creations, she felt this was fundamentally different as more of a guided tour rather than a showcase. Several instructors moved to asynchronous means of sharing and commenting on these artefacts. P4 explains that students would create storyboard sketches in slide decks, where each project link was put into a shared spreadsheet "The idea is people would just go click on these on their own, and then they would have to leave comments in a Google doc. For that in class activity, we completely lost any sort of real time-ness."

For some activities, capturing the experience of the artifact was difficult. P12 describes the experience of trying to understand a haptic VR experience designed by students in his class: "Sadly we only saw the VR part, but they explained before via pictures and slides how the concept was working." In this case, no other student was able to understand or experience the artefact in its entirety.

In-person hands-on activities are often designed such that students can also easily see what others are doing. While not explicitly part of the tasks within an activity, instructors understand that as students engage with their own activities, they will also wander the room occasionally. Here, as they mill about, they will casually look at what others are doing, and exchange ideas. We can see from previous examples that while some instructors used "shared dropboxes" to collect other students' work, students would need to explicitly engage with these rather than simply casually seeing them.

Furthermore, with the video-conferencing tools instructors used, students were unable to set up alternate communication channels without the intervention of an instructor. For example, remote calling applications like Zoom supported subgroup creation through the deliberate and structured creation of breakout rooms. These rooms and the participants in each room are created and managed by the host of the call. Participants in the rooms only had the choice to join the room to which they are assigned, or to leave the room and be placed back into the main public room. Students could employ text-based chat in many of these tools (or alternate tools altogether) as backchannels [35]; however, these are considerably more cumbersome than speaking, and the text chat did not work between rooms. Furthermore, while it was possible to specify "receivers" for these text messages (for example, a subgroup of students for the messages) doing so is time-consuming, and ultimately was rarely used according to our participants.

4.4 Allowing students to acquire tacit knowledge by observing critiques and feedback (PG4)

In-person hands-on activities also promote tacit knowledge acquisition without the need for explicit communication. When instructors provide critique or feedback to one student team publicly, the expectation is that other student teams can use this to acquire a deeper understanding of the task at hand, or how to improve their own work. In this sense, being able to see instructor's interactions with other students aids the class in self-regulation.

Seven instructors reported giving feedback in hands-on activities with the expectation that other students may overhear the interaction. In some cases, the expectation may be that other students can learn something from this interaction. For instance P10 recalls: "I would always tell the rest of the students that that if I'm helping one student, then it's valuable information for everyone else. They should see how I approach a problem, and what questions I ask." Sometimes, this would be done very deliberately for the entire class's benefit, where P10 reports, "They would be scrolling through the program, and I would say 'Go up a bit to that line right there,' so everyone could see that and hear my explanation." Other students can learn and acquire this knowledge simply through observing the instructor's interactions with other students.

To be clear, as reported by one instructor, this broadcast from an instructor is not always relevant to all students. In an in-person context, an instructor can make the contextual decision to modulate her voice so that it is heard by just a single student, a student group, nearby groups, or the entire class. In the online context, this was made more cumbersome with the breakout rooms that would enable only a per-group or a whole-class interaction. P5 opted for breakout room discussions only, since, "I didn't feel like the other students gain much from hearing about the other students' projects." This is due in large part to the fact that there are no easy ways to transition between group-only versus whole-class.

5 OPPORTUNITIES FOR EFFECTIVELY SUPPORTING HANDS-ON ACTIVITIES ONLINE

Using hands-on activities in online classes with current tools is a challenging proposition for both instructors and students. As we have described above, instructors have pedagogical goals inadequately addressed by current video-conferencing tools. According to instructors, this affects students' learning as these online activities are not as fruitful as their in-person counterparts. Here, we present design recommendations based on our analysis to give guidance to designers and developers who are improving existing technologies, or are ideating on how to design the next generation of online learning tools for hands-on activities.

Provide flexible awareness of all student activity within the class. Instructors need the ability to monitor student activity and progress as they engage in hands-on activities in order to adapt their interventions (PG1). In conventional face-to-face contexts, instructors engage in casual "walk-arounds", where they wander around a room, looking at both the student's activity, as well as their body language to assess whether students are stuck or not progressing well.

This awareness could therefore focus on either body language or workspace activity (or both). A straightforward approach would simply be to allow the instructor to see every student's camera feed and screen share within each group. Yet, this approach may be challenging for the instructor to interpret with even a moderately large class. It may be thus useful to consider abstractions: for instance, instead of showing the workspace itself, a system could show how much progress a student (or student group) has made in the activity; similarly, instead of showing webcam feeds of all students, a system could show abstract representations of students' facial expressions, who is talking, or what students are looking at (akin to [83] or [79]). These abstract cues may provide sufficient awareness for an instructor to understand the state of the classroom and its dynamics.

This view of the classroom should also be flexible in allowing the instructor to decide how closely she needs to monitor different groups or different elements in a group. In practice, instructors do not need to pay close attention to all groups; thus, for some groups, perhaps being able to see the cameras or screen shares is important, while for others, an abstract set of cues is sufficient. Furthermore, some activities may be more focused on the creation or modification of an artefact, while others are more focused on conversation. Providing this awareness for monitoring activity around physical artefacts is more complex, though based on our interviews, students frequently turned their webcams to allow the instructor to visualize the physical artefact.

Allow for permeable, flexible spaces for work and interaction. Current video-conferencing tools employ "breakout rooms", which emphasize the impermeable walls and doors of the room. Based on our findings, we advocate instead for semi-permeable spaces—both in terms of being able to see and hear "out" of the space, as well as to being able to see and hear "into" the space. The metaphor we recommend is a large open space with smaller areas where groups can gather to hear one another or to see a shared workspace.

This permeability would enable instructors to smoothly transition between working with one group to another. Further, it would provide a sort of interstitial space where instructors are not working with any particular group, thereby giving students the ability to signal for assistance. Additionally, it would enable students to opportunistically pull the instructor aside to ask a question as they would be aware when the instructor is "free". Giving students an awareness of what instructors are doing helps students understand why an instructor is or is not responding, and allows students to time their requests to opportune moments. Students might also be able to take advantage of this semi-permeability for working with an instructor as well: if an instructor were working with a given student group, another student could wait just at the periphery of the group to "listen in" on the advice of the instructor (PG4).

Finally, the fact that spaces are effectively permeable allows them to be rapidly created and dissolved on an as needed basis. Thus, if students want to have a quick aside without disturbing others, they can do so without the intervention of an instructor (PG3).

Supporting remote gesture on both freeze-frame and live video annotation. Providing guidance and feedback on students' artefacts (PG2) is essential to instructors, but is challenging in an online context as hands-on activities may involve several of types of artifacts. Digital artifacts are more easily shareable because people can screen share and in some instances they may even be able to give remote control. However, providing proper mechanisms for others to properly visualize and manipulate physical artifacts is very challenging, and effective tools for supporting this kind of interaction are very complex (e.g. remotely controlled robotic arm, using mixed reality) and not ubiquitous, which would make their adoption in an educational context very difficult in the near feature.

Yet, there are a number of straightforward augmentations to conventional video-conferencing software that could easily support communication around such artefacts. First, it would be useful if users could freeze video or screen shares in real-time, or review previous videos to freeze (and subsequently share). Such a series of frozen screenshots could be used to explain a problem or to understand how to fix a problem with an artefact, without requiring a student to hold the artefact in front of the camera. Second, it would be useful to be able to annotate such frozen video feeds (akin to [16]), or to annotate the live video (akin to [59]). Such mechanisms allow both instructors and students with the ability to gesture remotely, allowing participants to establish common ground by having the ability to draw which would facilitate the use of deixis (e.g. "move this wire there", "can you move it to this side"). This has been explored by prior work but it has yet to be implemented in common video-conferencing software.

While a number of other creative approaches have been explored in the literature, many of these require specialized or external equipment (e.g. external projectors, AR/VR equipment, etc.) that are likely beyond the reach of most distance schooling setups for the foreseeable future.

6 DISCUSSION AND FUTURE WORK

The COVID-19 pandemic forced unprepared instructors onto platforms ill-equipped for hands-on activities, revealing the subtle ways in which the orchestration of hands-on activities supports learning. Our interviews uncovered ways in which existing commercial tools do not fully address instructors' pedagogical goals (indeed, the problems of Xoom from our motivating scenario are plainly obvious through the perspective of pedagogical goals), allowing us to refine our understanding of how hands-on activities can be better supported in online teaching spaces. Connecting our findings to the general knowledge on computer-mediated communication we show how the video-conferencing tools used for hands-on activities failed to provide sufficiently rich media channel for communication in the complex learning tasks. In particular, we see show the key aspects of rich media—feedback capacity, individual focus, and diversity of communication cues [10, 66]—were not supported sufficiently from the instructors' perspectives. Insufficient media richness resulted in the particular way the instructors formulated their articulation of their pedagogical goals, focusing on increased tracking of the students' progress (PG1), providing larger amount of verbal feedback (PG2), and enabling students to observe critique and feedback of their peers (PG4).

We also saw how the inability of the video-conferencing medium to enable mutual awareness of the participants led the instructors to underscore the need for enhancing students' ability to observe others while working (PG3). Mutual awareness, in particular consequential communication such as the information that originated from observing individuals' activities in the workspace, [24, 26] is an important source of implicit feedback in the context of hands-on learning activities. In contrast to physical classrooms and maker spaces, in our observations, the students were not able to implicitly observe each other's activities while working. Insufficient mutual awareness necessitated scaling down the group-based learning tasks, negatively affecting pedagogical goals of the instructors.

We outline some limitations of our work here:

- **Instructor-only perspective.** Our analysis was informed strictly by the instructors' perspectives and did not consider the learners' point of view. While this focus allowed us to discuss the pedagogical intent of the instructors, because our data is strictly based on retrospective anecdotes drawn from instructors' experiences, we could not describe within-group student-to-student interactions at length. While we expect instructors to be critical in their reflections on their teaching practices, they may have misremembered events or the efficacy of certain practices. Furthermore, learners' perspectives are not accounted for in our approach—specifically, learners' physical or hardware setups, or other obligations (e.g. family) could fundamentally impact how they can learn effectively in an online context. We could overcome this in the future through direct observation of hands-on activities or interviews with instructors during the term. We intend to refine our understanding by studying student group dynamics and learners' perspectives on these hands-on activities in future work, and encourage other researchers to do so as well.

- **Focus on specific activities in computing and HCI post-secondary education.** Our sample focused on particular types of hands-on activities that are common in university computing and HCI courses. In particular, our sample included instructors delivering hands-on activities that could practically be executed at home (e.g., on a computer or a physical table with objects that could be found in learners' homes). Many hands-on activities cannot be supported remotely in at-home environments: some disciplines rely on laboratory equipment, safety protocols, reagents, or specimens. Furthermore, instructors for elementary or secondary education contexts may have other pedagogical goals altogether. Other disciplines (e.g. health sciences) may have other kinds of needs or educational goals that cannot be effectively addressed by the design suggests we articulate above. Thus, we encourage future researchers to consider an even broader range of hands-on activities from a more diverse disciplinary set. This would help inform broader discussions about how video-conferencing technologies could be designed to support learning and teaching online.
- **Pandemic perspective.** Our study took advantage of the COVID-19 pandemic, where we interviewed instructors who needed to move hands-on courses to online delivery on short notice. Thus, their experiences could be argued as subpar: had instructors intended to deliver courses remotely at the outset, they likely would have planned their courses better with the tools at hand. However, this planning around the available tools may be misaligned with the broader educational philosophy. The instructors have pedagogical goals that they are trying to achieve, and the tools should support these goals. Our interviews and interventions occurred at a timely moment where these pedagogical goals could still be identified clearly, and the challenges posed by existing tools were made very clear. Had our analysis been conducted with instructors who had built courses from the ground-up with remote delivery in mind, the pedagogical goals would have been already compromised to suit the affordances of existing platforms, rather than reflecting instructors' actual desired needs.

To conclude, we identify four pedagogical goals that instructors have for hands-on activities, and describe how these are inadequately addressed through existing video-conferencing technologies. By articulating and understanding these goals, we provide clear design guidance for the next generation of video-conferencing tools for educational use. Given that the hands-on activities are a valuable part of an instructor's arsenal, it is essential to support them in future tools, as online teaching gains momentum in the post-COVID world.

REFERENCES

[1] Hamed S. Alavi and Pierre Dillenbourg. 2012. An Ambient Awareness Tool for Supporting Supervised Collaborative Problem Solving. 5, 3 (2012), 264–274. https://doi.org/10.1109/TLT.2012.7
[2] Terry Anderson. 2004. Teaching in an online learning context. *Theory and practice of online learning* 273 (2004).

[3] Mark Apperley, Laurie McLeod, Masood Masoodian, Lance Paine, Malcolm Phillips, Bill Rogers, and Kirsten Thomson. 2003. Use of Video Shadow for Small Group Interaction Awareness on a Large Interactive Display Surface. In *Proceedings of the Fourth Australasian user interface conference on User interfaces 2003* (Adelaide, Australia) *(AUIC '03, Vol. 18)*. Australian Computer Society, Inc., 81–90. https://doi.org/10.5555/820086.820107

[4] Chulakorn Aritajati and N. Hari Narayanan. 2013. Facilitating Students' Collaboration and Learning in a Question and Answer System. In *Proceedings of the 2013 Conference on Computer Supported Cooperative Work Companion* (San Antonio, Texas, USA) *(CSCW '13)*. ACM Press, 101–106. https://doi.org/10.1145/2441955.2441983

[5] MS Balaji and Diganta Chakrabarti. 2010. Student interactions in online discussion forum: Empirical research from'media richness theory'perspective. *Journal of interactive online learning* 9, 1 (2010).

[6] Gabrielle Benabdallah, Sam Bourgault, Nadya Peek, and Jennifer Jacobs. 2021. Remote Learners, Home Makers: How Digital Fabrication Was Taught Online During a Pandemic. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 350, 14 pages. https://doi.org/10.1145/3411764.3445450

[7] Mark Billinghurst and Hirokazu Kato. 2002. Collaborative Augmented Reality. 45, 7 (2002), 64–70. https://doi.org/10.1145/514236.514265

[8] Baiyun Chen, Kathleen Bastedo, and Wendy Howard. 2018. Exploring Design Elements for Online STEM Courses: Active Learning, Engagement & Assessment Design. 22, 2 (2018), 59–76. https://doi.org/10.24059/olj.v22i2.1369

[9] Zhilong Chen, Hancheng Cao, Yuting Deng, Xuan Gao, Jinghua Piao, Fengli Xu, Yu Zhang, and Yong Li. 2021. Learning from Home: A Mixed-Methods Analysis of Live Streaming Based Remote Education Experience in Chinese Colleges during the COVID-19 Pandemic. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 348, 16 pages. https://doi.org/10.1145/3411764.3445428

[10] Richard L Daft and Robert H Lengel. 1983. *Information richness. A new approach to managerial behavior and organization design.* Technical Report. Texas A and M Univ College Station Coll of Business Administration.

[11] Alan Dix, Janet Finlay, Gregory Abowd, and Russel Beale. 1997. *Human-Computer Interaction.* Prentice-Hall, Inc.

[12] Paul Dourish and Victoria Bellotti. 1992. Awareness and coordination in shared workspaces. In *Proceedings of the 1992 ACM conference on Computer-supported cooperative work*. 107–114.

[13] Paul Dourish and Sara Bly. 1992. Portholes: Supporting Awareness in a Distributed Work Group. In *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '92* (Monterey, California, United States) *(CHI '92)*. ACM Press, 541–547. https://doi.org/10.1145/142750.142982

[14] Barrett Ens, Joel Lanir, Anthony Tang, Scott Bateman, Gun Lee, Thammathip Piumsomboon, and Mark Billinghurst. 2019. Revisiting collaboration through mixed reality: The evolution of groupware. 131 (2019), 81–98. https://doi.org/10.1016/j.ijhcs.2019.05.011

[15] Katherine M Everitt, Scott R Klemmer, Robert Lee, and James A Landay. 2003. Two Worlds Apart: Bridging the Gap Between Physical and Virtual Media for Distributed Design Collaboration. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Ft. Lauderdale, Florida, USA) *(CHI '03)*. ACM Press, 553–560. https://doi.org/10.1145/642611.642707

[16] Omid Fakourfar, Kevin Ta, Richard Tang, Scott Bateman, and Anthony Tang. 2016. Stabilized Annotations for Mobile Remote Assistance. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose California USA) *(CHI '16)*. Association for Computing Machinery, 1548–1560. https://doi.org/10.1145/2858036.2858171

[17] Deborah A Fields, Gayithri Jayathirtha, and Yasmin B Kafai. 2019. Bugs as a Nexus for Emergent Peer Collaborations: Contextual and Classroom Supports for Solving Problems in Electronic Textiles. In *13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019* (Lyon, France) *(CSCL '19, Vol. 1)*. International Society of the Learning Sciences, 472–479. https://doi.org/10.22318/cscl2019.472

[18] Susan R Fussell, Leslie D Setlock, and Robert E Kraut. 2003. Effects of Head-Mounted and Scene-Oriented Video Systems on Remote Collaboration on Physical Tasks. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Ft. Lauderdale, Florida, USA) *(CHI '03)*. Association for Computing Machinery, 513–520. https://doi.org/10.1145/642611.642701

[19] Bijan B Gillani and Anju Relan. 1997. Incorporating interactivity and multimedia into web-based instruction. *Web-based instruction* (1997), 231–237.

[20] Saul Greenberg and Michael Rounding. 2001. The Notification Collage: Posting Information to Public and Personal Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Seattle, Washington, United States) *(CHI '01)*. Association for Computing Machinery, 514–521. https://doi.org/10.1145/365024.365339

[21] Raja Gumienny, Lutz Gericke, Matthias Wenzel, and Christoph Meinel. 2013. Supporting creative collaboration in globally distributed companies. In *Proceedings of the 2013 conference on Computer supported cooperative work*. 995–1007.

[22] Philip J. Guo, Jeffery White, and Renan Zanelatto. 2015-10. Codechella: Multi-user program visualizations for real-time tutoring and collaborative learning. In *2015 IEEE Symposium on Visual Languages and Human-Centric Computing*

(VL/HCC) (Atlanta, GA). IEEE, 79–87. https://doi.org/10.1109/VLHCC.2015.7357201

[23] Carl Gutwin and Saul Greenberg. 2000. The Mechanics of Collaboration: Developing Low Cost Usability Evaluation Methods for Shared Workspaces. In *Proceedings of the 9th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises* (Gaithersburg, MD, USA) *(WETICE '00)*. IEEE Computer Society, 98–103. https://doi.org/10.5555/647068.715651

[24] Carl Gutwin and Saul Greenberg. 2002. A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Comput. Supported Coop. Work* 11, 3 (Nov. 2002), 411–446. https://doi.org/10.1023/A:1021271517844

[25] Carl Gutwin and Saul Saul Greenberg. 1998. Design for individuals, design for groups: tradeoffs between power and workspace awareness. In *Proceedings of the 1998 ACM conference on Computer supported cooperative work* (New York, NY, USA) *(CSCW '98)*. Association for Computing Machinery, 207–216.

[26] Carl Gutwin and Saul Saul Greenberg. 2002. Design for individuals, design for groups: tradeoffs between power and workspace awareness. In *Proceedings of the 2002 ACM conference on Computer supported cooperative work* (New York, NY, USA) *(CSCW '02)*. Association for Computing Machinery, 411–446.

[27] Mark Guzdial. 2017. Balancing Teaching CS Efficiently with Motivating Students. *Commun. ACM* 60, 6 (May 2017), 10–11. https://doi.org/10.1145/3077227

[28] Oliver L Haimson and John C Tang. 2017. What makes live events engaging on Facebook Live, Periscope, and Snapchat. In *Proceedings of the 2017 CHI conference on human factors in computing systems*. 48–60.

[29] Wissam Halimi, Christophe Salzmann, and Denis Gillet. 2017. Access to Massive Open Online Labs through a MOOC. In *Proceedings of the Fourth (2017) ACM Conference on Learning @ Scale* (Cambridge, Massachusetts, USA) *(L@S '17)*. Association for Computing Machinery, 331–334. https://doi.org/10.1145/3051457.3054017

[30] Erica Halverson, Breanne Litts, and Brian Gravel. 2018. Forms of Emergent Collaboration in Maker-based learning. In *Proceedings of the International Conference of the Learning Sciences*. 921–924.

[31] Edwin Hutchins. 1995. *Cognition in the wild.* The MIT Press.

[32] Hiroshi Ishii and Minoru Kobayashi. 1992. ClearBoard: A Seamless Medium for Shared Drawing and Conversation with Eye Contact. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Monterey, California, United States) *(CHI '92)*. Association for Computing Machinery, 525–532. https://doi.org/10.1145/142750.142977

[33] Gayithri Jayathirtha, Deborah Fields, Yasmin B. Kafai, and Joseph Chipps. 2020. Supporting making online: the role of artifact, teacher and peer interactions in crafting electronic textiles. 121, 5 (2020), 381–390. https://doi.org/10.1108/ILS-04-2020-0111

[34] David W. Johnson and Roger T. Johnson. 1999. Making cooperative learning work. *Theory Into Practice* 38, 2 (1999), 67–73. https://doi.org/10.1080/00405849909543834 arXiv:https://doi.org/10.1080/00405849909543834

[35] Wendy A. Kellogg, Thomas Erickson, Tracee Vetting Wolf, Stephen Levy, Jim Christensen, Jeremy Sussman, and William E. Bennett. 2006. Leveraging Digital Backchannels to Enhance User Experience in Electronically Mediated Communication. In *Proceedings of the 2006 20th Anniversary Conference on Computer Supported Cooperative Work* (Banff, Alberta, Canada) *(CSCW '06)*. Association for Computing Machinery, 451–454. https://doi.org/10.1145/1180875.1180943

[36] Vichuda Nui Kettanurak, K Ramamurthy, and William D Haseman. 2001. User attitude as a mediator of learning performance improvement in an interactive multimedia environment: An empirical investigation of the degree of interactivity and learning styles. *International Journal of Human-Computer Studies* 54, 4 (2001), 541–583.

[37] David Kirk and Danae Stanton Fraser. 2006. Comparing Remote Gesture Technologies for Supporting Collaborative Physical Tasks. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Montréal, Québec, Canada) *(CHI '06)*. Association for Computing Machinery, 1191–1200. https://doi.org/10.1145/1124772.1124951

[38] Joseph S. Krajcik and Phyllis C. Blumenfeld. 2006. *The Cambridge Handbook of the Learning Sciences.* Cambridge University Press.

[39] Takeshi Kurata, Nobuchika Sakata, Masakatsu Kourogi, Hideaki Kuzuoka, and Mark Billinghurst. 2004. Remote Collaboration using a Shoulder-Worn Active Camera/Laser. In *Proceedings of the Eighth International Symposium on Wearable Computers* (Arlington, VA, USA) *(ISWC '04)*. IEEE Computer Society, 62–69. https://doi.org/10.1109/ISWC.2004.37

[40] Tony Lawson, Chris Comber, Jenny Gage, and Adrian Cullum-Hanshaw. 2010. Images of the future for education? Videoconferencing: A literature review. *Technology, pedagogy and education* 19, 3 (2010), 295–314.

[41] Gun A. Lee, Theophilus Teo, Seungwon Kim, and Mark Billinghurst. 2017. Sharedsphere: MR Collaboration through Shared Live Panorama. In *SIGGRAPH Asia 2017 Emerging Technologies* (Bangkok, Thailand) *(SA '17)*. Association for Computing Machinery. https://doi.org/10.1145/3132818.3132827

[42] Christian Licoppe, Paul K. Luff, Christian Heath, Hideaki Kuzuoka, Naomi Yamashita, and Sylvaine Tuncer. 2017. Showing Objects: Holding and Manipulating Artefacts in Video-Mediated Collaborative Settings. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, 5295–5306. https://doi.org/10.1145/3025453.3025848

[43] Yu-Tzu Lin, Cheng-Chih Wu, and Chiung-Fang Chiu. 2018. The Use of Wiki in Teaching Programming: Effects Upon Achievement, Attitudes, and Collaborative Programming Behaviors. *Int. J. Distance Educ. Technol.* 16, 3 (July 2018), 18–45. https://doi.org/10.4018/IJDET.2018070102

[44] Michelle Lui, Alex C. Kuhn, Alisa Acosta, Chris Quintana, and James D. Slotta. 2014. Supporting Learners in Collecting and Exploring Data from Immersive Simulations in Collective Inquiry. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, 2103–2112. https://doi.org/10.1145/2556288.2557162

[45] Jane Margolis and Joanna Goode. 2016. Ten Lessons for Computer Science for All. 7, 4 (2016), 52–56. https://doi.org/10.1145/2988236

[46] Lee Martin. 2015. The Promise of the Maker Movement for Education. 5, 1 (2015). https://doi.org/10.7771/2157-9288.1099

[47] Roberto Martinez-Maldonado, Judy Kay, Kalina Yacef, Marie-Theresa Edbauer, and Yannis Dimitriadis. 2013. MTClassroom and MTDashboard: Supporting Analysis of Teacher Attention in an Orchestrated Multi-tabletop Classroom. In *10th International Conference on Computer-Supported Collaborative Learning* (Madison, USA) *(CSCL 2013, Vol. 1)*. International Society of the Learning Sciences, 9.

[48] Alexander McAuley, Bonnie Stewart, George Siemens, and Dave Cormier. 2010. The MOOC model for digital practice. (2010).

[49] Joseph F McCarthy, Ben Congleton, and F Maxwell Harper. 2008. The Context, Content & Community Collage: Sharing Personal Digital Media in the Physical Workplace. In *Proceedings of the 2008 ACM Conference on Computer Supported Cooperative Work* (San Diego, CA, USA) *(CSCW '08)*. Association for Computing Machinery, 97–106. https://doi.org/10.1145/1460563.1460580

[50] D. Scott McCrickard, C. M. Chewar, and Jacob Somervell. 2004. Design, Science, and Engineering Topics? Teaching HCI with a Unified Method. In *Proceedings of the 35th SIGCSE Technical Symposium on Computer Science Education* (Norfolk, Virginia, USA) *(SIGCSE '04)*. Association for Computing Machinery, New York, NY, USA, 31–35. https://doi.org/10.1145/971300.971314

[51] Gregor McEwan and Saul Greenberg. 2005. Supporting social worlds with the community bar. In *Proceedings of the 2005 International ACM SIGGROUP Conference on Supporting Group Work* (Sanibel Island, Florida, USA) *(GROUP '05)*. Association for Computing Machinery, 21–30. https://doi.org/10.1145/1099203.1099207

[52] Larry K. Michaelsen, L. Dee Fink, and Arietta Knight. 1997. Designing Effective Group Activities: Lessons for Classroom Teaching and Faculty Development. 16, 1 (1997), 373–397. https://doi.org/10.1002/j.2334-4822.1997.tb00335.x

[53] Nadia S. Molina-Moreno, Maria S. Avila-Garcia, Marco Bianchetti, David Claudio-Gonzalez, and Marcelina Pantoja-Flores. 2017. Impact of Technology in Collaborative and Interactive Programming Activities: Gathering Children's Feedback. In *2017 5th International Conference in Software Engineering Research and Innovation (CONISOFT)*. 179–183. https://doi.org/10.1109/CONISOFT.2017.00029

[54] Julia Mullen, Lauren Milechin, and Albert Reuther. 2019. Cultivating professional technical skills and understanding through hands-on online learning experiences. In *2019 IEEE Learning With MOOCS (LWMOOCS)* (Milwaukee, WI, USA). IEEE, 150–155. https://doi.org/10.1109/LWMOOCS47620.2019.8939637

[55] Carman Neustaedter, Samarth Singhal, Rui Pan, Yasamin Heshmat, Azadeh Forghani, and John Tang. 2018. From Being There to Watching: Shared and Dedicated Telepresence Robot Usage at Academic Conferences. 25, 6 (2018), 1–39. https://doi.org/10.1145/3243213

[56] Alannah Oleson, Meron Solomon, and Amy J. Ko. 2020. *Computing Students' Learning Difficulties in HCI Education.* Association for Computing Machinery, New York, NY, USA, 1–14. https://doi.org/10.1145/3313831.3376149

[57] Alannah Oleson, Brett Wortzman, and Amy J. Ko. 2021. On the Role of Design in K-12 Computing Education. *ACM Trans. Comput. Educ.* 21, 1, Article 2 (Dec. 2021), 34 pages. https://doi.org/10.1145/3427594

[58] Edeh Michael Onyema, Edeh Chinecherem Deborah, Alhuseen Omar Alsayed, Quadri Noorulhasan, and Sumaya Sanober Naveed. 2019. Online discussion forum as a tool for interactive learning and communication. *International Journal of Recent Technology and Engineering* 8, 4 (2019), 4852–4859.

[59] Jiazhi Ou, Xilin Chen, Susan R Fussell, and Jie Yang. 2003. DOVE: Drawing over Video Environment. In *Proceedings of the Eleventh ACM International Conference on Multimedia* (Berkeley, CA, USA) *(MULTIMEDIA '03)*. Association for Computing Machinery, 100–101. https://doi.org/10.1145/957013.957034

[60] Thammathip Piumsomboon, Gun A. Lee, Jonathon D. Hart, Barrett Ens, Robert W. Lindeman, Bruce H. Thomas, and Mark Billinghurst. 2018. Mini-Me: An Adaptive Avatar for Mixed Reality Remote Collaboration. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. ACM Press, 1–13. https://doi.org/10.1145/3173574.3173620

[61] Ronald E Rice. 1992. Task analyzability, use of new media, and effectiveness: A multi-site exploration of media richness. *Organization science* 3, 4 (1992), 475–500.

[62] Sandra Schulz and Andreas Lingnau. 2020. An Evidence-Based Learner Model for Supporting Activities in Robotics. In *Proceedings of the Seventh ACM Conference on Learning @ Scale* (Virtual Event, USA) *(L@S '20)*. Association for Computing Machinery, New York, NY, USA, 397–400. https://doi.org/10.1145/3386527.3406760

[63] Abigail Sellen, Bill Buxton, and John Arnott. 1992. Using spatial cues to improve videoconferencing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Monterey, California, United States) *(CHI '92)*. ACM Press, 651–652. https://doi.org/10.1145/142750.143070

[64] Morgan M Shepherd and Wm Benjamin Martz Jr. 2006. Media richness theory and the distance education environment. *Journal of Computer Information Systems* 47, 1 (2006), 114–122.

[65] Joshua Shi, Armaan Shah, Garrett Hedman, and Eleanor O'Rourke. 2019. *Pyrus: Designing A Collaborative Programming Game to Promote Problem Solving Behaviors*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300886

[66] Kil Soo Suh. 1999. Impact of communication medium on task performance and satisfaction: an examination of media-richness theory. *Information & Management* 35, 5 (1999), 295–312.

[67] Hongling Sun, Zhenliang Zhang, Yue Liu, and Henry B. L. Duh. 2016. OptoBridge: assisting skill acquisition in the remote experimental collaboration. In *Proceedings of the 28th Australian Conference on Computer-Human Interaction* (Launceston, Tasmania, Australia) *(OzCHI '16)*. ACM Press, 195–199. https://doi.org/10.1145/3010915.3010975

[68] Pei-Chen Sun and Hsing Kenny Cheng. 2007. The design of instructional multimedia in e-Learning: A Media Richness Theory-based approach. *Computers & education* 49, 3 (2007), 662–676.

[69] Anthony Tang, Carman Neustaedter, and Saul Greenberg. 2007. VideoArms: Embodiments for Mixed Presence Groupware. In *People and Computers XX — Engage*, Nick Bryan-Kinns, Ann Blanford, Paul Curzon, and Laurence Nigay (Eds.). Springer London, 85–102. https://doi.org/10.1007/978-1-84628-664-3_8

[70] Anthony Tang, Michel Pahud, Kori Inkpen, Hrvoje Benko, John C. Tang, and Bill Buxton. 2010. Three's company: understanding communication channels in three-way distributed collaboration. In *Proceedings of the 2010 ACM conference on Computer supported cooperative work* (Savannah, Georgia, USA) *(CSCW '10)*. ACM Press, 271–280. https://doi.org/10.1145/1718918.1718969

[71] John C. Tang and Scott Minneman. 1991. VideoWhiteboard: video shadows to support remote collaboration. In *Proceedings of the SIGCHI conference on Human factors in computing systems Reaching through technology - CHI '91* (New Orleans, Louisiana, United States). ACM Press, 315–322. https://doi.org/10.1145/108844.108932

[72] John C. Tang and Scott L. Minneman. 1990. VideoDraw: A Video Interface for Collaborative Drawing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Seattle, Washington, USA) *(CHI '90)*. Association for Computing Machinery, 313–320. https://doi.org/10.1145/97243.97302

[73] Richard Tang, Xing-Dong Yang, Scott Bateman, Joaquim Jorge, and Anthony Tang. 2015. Physio@Home: Exploring Visual Guidance and Feedback Techniques for Physiotherapy Exercises. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. ACM Press, 4123–4132. https://doi.org/10.1145/2702123.2702401

[74] Josh Tenenberg. 2016. Learning through observing peers in practice. *Studies in Higher Education* 41, 4 (2016), 756–773. https://doi.org/10.1080/03075079.2014.950954

[75] Linda Klebe Trevino, Robert H Lengel, and Richard L Daft. 1987. Media symbolism, media richness, and media choice in organizations: A symbolic interactionist perspective. *Communication research* 14, 5 (1987), 553–574.

[76] Despina Tsompanoudi, Maya Satratzemi, and Stelios Xinogalos. 2016. Evaluating the Effects of Scripted Distributed Pair Programming on Student Performance and Participation. *IEEE Transactions on Education* 59, 1 (2016), 24–31. https://doi.org/10.1109/TE.2015.2419192

[77] Gina Venolia, John Tang, Ruy Cervantes, Sara Bly, George Robertson, Bongshin Lee, and Kori Inkpen. 2010. Embodied social proxy: mediating interpersonal connection in hub-and-satellite teams. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Atlanta, Georgia, USA) *(CHI '10)*. Association for Computing Machinery, 1049–1058. https://doi.org/10.1145/1753326.1753482

[78] L.S. Vygotsky, M. Cole, V. John-Steiner, S. Scribner, and E. Souberman. 1978. *Mind in Society: Development of Higher Psychological Processes*. Harvard University Press. https://books.google.ca/books?id=RxjjUefze_oC

[79] Shuo-Ping Wang, Mei-Ling hen, Hao-Chuan Wang, Chien-Tung Lai, and Ai-Ju Huang. 2017. De-Identified Feature-Based Visualization of Facial Expression for Enhanced Text Chat. In *Proceedings of the 43rd Graphics Interface Conference* (Edmonton, Alberta, Canada) *(GI '17)*. Canadian Human-Computer Communications Society, Waterloo, CAN, 199–207.

[80] Laurie A. Williams and Robert R. Kessler. 2000. All I Really Need to Know about Pair Programming I Learned in Kindergarten. *Commun. ACM* 43, 5 (May 2000), 108–114. https://doi.org/10.1145/332833.332848

[81] Marcelo Worsley and Paulo Blikstein. 2014. The impact of principle-based reasoning on hands-on, project-based learning. In *11th International Conference of the Learning Sciences: Learning and Becoming in Practice, ICLS 2014* (Boulder, United States), Vol. 2. International Society of the Learning Sciences (ISLS), 1147–1151.

[82] Masanori Yamada. 2009. The role of social presence in learner-centered communicative language learning using synchronous computer-mediated communication: Experimental study. *Computers & Education* 52, 4 (2009), 820–833.
[83] Matin Yarmand, Jaemarie Solyst, Scott Klemmer, and Nadir Weibel. 2021. "It Feels Like I Am Talking into a Void": Understanding Interaction Gaps in Synchronous Online Classrooms. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 351, 9 pages. https://doi.org/10.1145/3411764.3445240
[84] Svetlana Yarosh, Anthony Tang, Sanika Mokashi, and Gregory D. Abowd. 2013. "almost touching": parent-child remote communication using the sharetable system. In *Proceedings of the 2013 conference on Computer supported cooperative work* (San Antonio, Texas, USA) *(CSCW '13)*. ACM Press, 181–192. https://doi.org/10.1145/2441776.2441798

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