Tech-Art-Theory: Improvisational Methods for HCI Learning and Teaching

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This paper explores the nature and potential of improvisation as a method for learning and teaching in CSCW and HCI. It starts by reviewing concepts of improvisational learning in classic and more recent work in educational theory, art and music, and HCI that emphasize the *reconstructive*, *materially-driven*, *error-engaged*, *transgressive*, and *collaborative* nature of human learning processes. It then describes three pedagogical interventions of our own in which improvisational techniques were deployed as methods of teaching and learning. From this integrated study, we report specific pedagogical conditions (*socio-material evaluations*, *multi-sensory practices*, and *making safe spaces for error*) that can support improvisational learning, and three common challenges of HCI pedagogy – *relevance*, *assessment*, and *inclusion* that improvisational methods can help to address.

CCS Concepts: • **Human-centered computing** • **Human computer interaction (HCI)** • **HCI theory, concepts and models**

KEYWORDS: Improvisation, Art, Music, Learning, Pedagogy, Performance, Ethnography

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1 INTRODUCTION

How can we learn and teach HCI through more improvisational and artistic methods? In more traditional representational theories, knowledge is sometimes assumed to be a reflective image of objective reality [89], and learning a kind of purposive action oriented to the transmission of essential facts, truths, or skills. Older and more structured educational methods built around this model have often approached teaching and learning as carefully ordered and controlled activities, with less appreciation for the role of emergent and circumstantial factors and forces shaping and defining interactive situations [13,69].

This perspective has been challenged and extended in recent decades by approaches grounded in constructivism [83], constructionism [81], and art-based inquiries [4,25,69], which approach human cognition and learning as concrete, situated, and sometimes fragile accomplishments. This underscores what we will call out as the improvisational quality of human knowledge and action, and how consciousness and the learning processes which produce it are reconstructed through

learner interactions with the infinite variety of the social and material worlds. This perspective has also opened up new approaches to learning, research and pedagogy in CSCW, HCI, and other fields, ranging from constructivist and practice-based design approaches to specific pedagogical forms – for example, apprenticeship and studio-based learning – in which individuals and groups learn through situated and (partly) open-ended interactions in specific socio-material environments.

In this paper, we argue that these approaches to learning can also benefit from theories and practices of improvisation, as defined and developed across a range of fields often held separate from CSCW and HCI scholarship. As deployed here, improvisation refers to the emergent and unscripted actions or performances that drive and derive from generative and open-ended interactions in local environments, departing from pre-formed plans or expectations [79,102]. Improvisational approaches are central to a variety of artistic fields, including contemporary art, music, and dance, as tools for resolving situated breakdowns and developing unanticipated modes of expression and creativity [8,71,101]. Beyond these fields, ideas and practices of improvisation have been employed across disciplines from the social sciences to engineering to highlight the contingent and evolutionary qualities of human cognition, discovery, and behavior [46,71].

In the field of CSCW and HCI, broadly improvisational perspectives on human cognition and learning have opened up important fronts in research and education. This includes theoretical work around the improvisational nature of human cognition and creativity in continuously changing socio-technical environments [2,27,78,113], and ethnographic studies of the role of social and material conditions in the process of knowledge construction and creativity [32,50,59,99]. Under different names and themes, the field has also explored more methodologically-focused approaches in which improvisational practices coupled with critical reflection studies are employed as more artistic, experience-based, and speculative modes of learning, teaching and research [38,39,52,73,90,107,123].

Our paper seeks to extend these lines of analysis through theoretical and ethnographic studies around improvisational learning and teaching. The main goals of this paper are to: (a) identify specific pedagogical conditions that can support improvisational learning in the context of CSCW and HCI; and (b) explain how such improvisational methods may help address existing challenges in HCI pedagogy. We begin by analyzing theoretical and methodological discussions of improvisation in education, the learning sciences, art, and music. From this, we emphasize the *reconstructive*, *materially-driven*, *error-engaged*, *transgressive*, and *collaborative* nature of improvisational learning. We also review how improvisational approaches have been deployed (sometimes under other names) in CSCW, HCI and design pedagogy to date. We then report empirical findings from our own series of teaching and learning interventions at the intersection of HCI, music, and art. In discussion, we describe some specific pedagogical conditions (*socio-material evaluations*, *multi-sensory practices*, and *making safe spaces for error*) that can support improvisational learning. Finally, we speak to three common challenges of HCI pedagogy – relevance, assessment, and inclusion – that improvisational learning approaches can help to address.

2 IMPROVISATIONAL LEARNING

Concepts broadly aligned with improvisational learning have long been central to education theory and the learning sciences, if rarely named as such. Classic learning theories from Piaget's constructivism [83] to Papert's constructionism [81] have emphasized the centrality of figurative thought and object engagement in the stage-wise development of cognitive capacity, along with

the processes of "accommodation" by which accepted "schema" – roughly, shared mental maps of the world – are tweaked and modified as individual learners build from distinct sensory experiences to higher forms of abstraction or "operational" thought. Work by Lev Vygotsky and followers in the Russian tradition of cultural-historical psychology (including its later framing under activity theory) has emphasized the mediating role of objects and accumulated cultural resources and artifacts in both individual ('ontogenetic') and species-level ('phylogenetic') development. In contrast to Piaget's emphasis on developmental stages, Vygotskian approaches have emphasized the presence and value of 'gaps' in the wider learning process, including what Vygotsky termed the 'zone of proximal development,' identified as a kind of hole or sweet spot between the current cognitive skills of learners and what could be achieved (and later internalized) under guidance and interaction with a supportive external environment [20,61,118]. Pragmatist theories of learning [25,26] have emphasized human learning as a holistic process of "trans-action" in which learners undergo the continuous reconstitution of experience through their constitutive interactions with others. Lave and Wenger build on such pragmatist foundations to emphasize the social and collective organization of learning, showing how the mastery of skills is bound up with identity, meaning, and the slow progression towards membership in "communities of practice" [68,120].

Such understandings of human learning have also been applied to more structured educational settings from pre-schools to universities. Exemplified in the U.S. most famously in the early twentieth-century Settlement House and Laboratory School experiments initiated by Jane Adams and John Dewey in Chicago, educators have explored alternative forms of classroom and curricular structure in which topics and structures emerge (or are "co-constructed") alongside students own distinct learning interests and approaches. These efforts have spawned a subsequent century-long proliferation of experiments in "alternative", "democratic", or "anti-oppressive" education that have grown up in conjunction with, and partial opposition to, the increasingly industrial scale of education ushered in by mandatory K-12 education and the post-war boom in college and university enrollments. By pointing out the problems of unilateral learning spaces built around scripted content and curricula – what Freire has criticized as the "banking model" of education [35] – recent scholars [29,37,75,77,82] have suggested metaphors for teaching ranging from "improvisational performance" [102] and "creative art" [13] to "disciplined improvisation [6]." Such metaphors highlight "the artful balance of structure and improvisation" [102] as an important source in enabling more creative learning environments. They are also often associated with a democratizing or leveling ambition, underlining the role of the teacher as a facilitator or "manager" [74] of the classroom experience, rather than an authoritative "creator" or "controller."

In short, what we call "improvisational learning" in this paper involves five common elements. The first is the belief that intuitive and open-ended activities can support processes of situated learning through *the reconstruction of experience.* As represented in various inquiry-based learning theories from constructivism to pragmatism to action learning [25,26,83,86,93,94], this approach recognizes the value of situated cognitive processes in which learners acquire knowledge through reflective, exploratory, and sometimes playful engagements with specific topics or problems. Individual histories and experiences are central to this process: rather than checking experience at the door or figuring learners as blank slates or empty vessels to be 'filled' with new knowledge, improvisational approaches encourage learners to bring in past perceptions, experiences, and distinct forms of care and commitment to the world as key motivations and resources for learning. This feature in turn may connect to more socio-politically grounded and engaged forms of

learning in which the needs and interests of learners and communities become key engines and shapers of the learning process, rather than details to be bracketed out [35].

Second, improvisational learning highlights the role of *material engagement* in the learning process. Echoing themes highlighted in constructionism [81] and recent post-humanist theories [10,67], improvisational learning calls attention to the significance of "making things" in learning [1] and the "agential" role of materials and other non-human actors [67] in shaping and enabling the learning encounter. In Actor-Network Theory, this agency is explained as a kind of relational effect, in which the identities and capacities of individual "agents" are neither fixed nor fully determined in advance, but "co-constructed" within concrete socio-material contexts and environments. This gives further weight to research and pedagogical approaches built around processes of material engagement, whether based in making, fixing, or iterative prototyping [54].

Third, improvisational learning frequently builds on and may be driven by *frictions, errors, and indeterminacies* in the local environment. As improvisational practitioners in art and music have highlighted – from John Cage's intention "to let things be themselves" [14] to Klemp et. al.'s observation that mistake "is the only way you can get to some place you've never been before" [65] – errors and breakdowns in the local environment can call forth unexpected moments of creativity and discovery. This perspective has been further developed in growing attention (in CSCW and elsewhere) to moments of productive failure, glitch, and repair and their role in processes of insight, learning, and discovery [49,55,62,98,112]. If such errors and failures make the process of learning riskier and less stable, they offer compensation in the form of surprising creativity and group emergence [8,65,100].

Fourth, improvisational methods may allow and encourage *transgressive* and in some instances *trouble-making* modes of expression that disrupt given rules, structures and accepted best practices. Jazz musicians for example may play disruptive 'blue notes' – a seventh in place of an expected octave, adjacent note pairs, etc. – that violate expectations of harmony and so upset the set-up of musical expectation [8,30]. Practitioners in socially-engaged art [43] have emphasized the beauty of "creative disruption" [11], and its standing "not [as] a mirror with which to reflect reality, but a hammer with which to shape it" [96]. In critical pedagogy, such anti-oppressive practices are encouraged for purposes of social critique, self-realization, and more interactive inquiries that aim to examine and challenge relations of power between learners, teachers, and wider social and educational systems [35,66]. While some critics have questioned whether higher educational institutions should play this disruptive or unsettling role [42,106], others have argued forcefully for learning spaces, including art studios, in which participants feel safe in "giving yourself over to what the activity provokes, and then following these possibilities assiduously" [4,64,114].

Finally, such reflexive, material, and emergent dimensions make improvisational learning essentially mutual and *collaborative* in nature, forgoing master plans designed by a central authority figure, in favor of a model in which the question of what is to be learned emerges over the course of interaction between situated actors (which can include non-human *things)* in the local environment [50,59,71,101]. This viewpoint naturally extends the process of learning from an isolated and individual activity to something more entangled, with learners and things collaborating to produce novel and otherwise unavailable results [32,33,50,56]. This runs against what Ingold [53] has criticized as the "hylopmorphic" model of creativity, in which creative action consists of the imposition of form on a mostly inert or passive field of matter; instead, "creativity is something we do *in* and *with* the world, not just to it" [56].

In this section, we reviewed theories of improvisational learning from various fields and identified its five common commitments. Like constructionism, improvisational learning highlights the ways in which human cognition and knowledge are continuously *reconstructed* through learner's experience. Like constructivism, improvisational learning invites *material* actors in the situation as collaborative partners that actively shape and influence cognitive and learning processes. But improvisational learning also brings new emphases and dynamics to attention. As theorists and practitioners of jazz and socially-engaged art have explained, the goal of improvisational practice is not 'correctness', but rather the ongoing building of capacity and imagination through the generation and repair of 'error' (whether emanating from mistake or more transgressive actions against accepted structure). It also offers a more expansively collaborative viewpoint on learning in which participants cognitions and expressions are not held separate, but constituted in interdependent interaction – with each other, and with the material worlds around them.

3 IMPROVISATIONAL LEARNING IN HCI AND CSCW

The same sense and tension has characterized CSCW and HCI work that has emphasized research and professional practice as itself grounded in processes of learning and reflection. For example, Donald Schön [104] has highlighted learning in design contexts as a process by which cognition, understanding, and imagination are continuously evolving through "reflective conversation" with the material world. In research through design [123], open-ended and inductive activities are highlighted as ways to explore "wicked problems" [95] that regularly defeat or resist more structured and linear approaches. Critical making [44,90], meta-design [39], and other constructionist methods [23,72,116] have highlighted hands-on activity, techno-material engagement, and participatory design to promote the integration of critical thinking, physical making, and creative design. Extending from ecological responsibility, recent sustainability-themed works have also called out the creativity embedded in the repairing and repurposing of broken or obsolete technologies [45,49,56,60,84]. 'Performance-led' [7], 'studio as laboratory' [28], and other art-based research approaches [47,50,58] have highlighted interdisciplinary learning opportunities through actual collaboration with artists, musicians, and dancers that support richer and more engaged forms of HCI research.

In the fields of HCI and computer science, improvisational principles and practices are also present (though not always called out as such) in studio-based and hybrid courses. These courses commonly highlight the advantage of learner-driven, making-based, and collaborative approaches that promote one's practical skill and creativity [9,15,18,87,91,117,121]. Some actively use interdisciplinary pedagogical forms and models by combining approaches from other fields including traditions of group critique, visual analysis, and socio-critical studies drawn from longer traditions in design, art, and the humanistic social sciences. For example, Prior et. al [88] have argued for studio-based models in HCI as a way of helping students deal with complex computational problems while building self-confidence and conviction in their own software design practices. Reimer et. al [92] have argued for iterative processes involving user feedback and testing as essential elements of HCI studio courses. Hundhausen et al.'s "Prototype Walkthrough" [52] has highlighted experimental and collaborative classroom settings in which student project teams simulate evolving user interface prototypes while a student audience member acts as a test user. Kafai et. al. [57] have underlined the need for "scaffolded challenges" and using electronic craft materials like e-textiles and Lilypad in introductory computing classes as a means broadening students' existing perceptions of computing.

However, even as these methods have become more widespread, they have encountered new challenges and tensions, some of them at the intersection of pedagogical technique, formal educational structures, and the boundaries and expectations of disciplines. For example, Oguamanam et al.'s study [80] of six computing classes integrating studio modes has shown how students trained in the culture of more traditional computing classrooms became "uncomfortable" in the studio setting. Exter et al.'s study [31] of an interdisciplinary HCI course co-taught by a multi-disciplinary team of instructors has shown how teachers from different backgrounds conceptualize 'design' differently, pointing out the problems and limits of mixing two or more disciplinary cultures in one learning space.

Similarly, questions around the assessment and evaluation of such ventures have continued to attract scrutiny or controversy. Where learning outcomes appear in provisional, materialized and 'out-of-the-box' forms, these may conflict with more universalist cultures of evaluation in computing and other STEM fields which favor clear interpretations, rationales, and contributions [37,48]. Where such variance occurs, researchers [12,36,41] have sometimes turned to devices like 'learning contracts' and 'annotated portfolios' as flexible but accountable mechanisms for evaluating learning outcomes. Sengers and Gaver [108] have also suggested alternative evaluation frameworks in which "multiple, potentially competing interpretations" can co-exist in a single design project to promote more complex and artistic aspects of research and design.

To sum up, a growing body of work in CSCW and HCI has explored and advocated for learning and teaching methods based on open-endedness, techno-material engagement, and interdisciplinary collaboration. But even as such improvisational methods have become more prevalent, they have faced questions and concerns around how to bring together and manage different disciplinary cultures in common learning spaces and how best to evaluate the outcomes from such modes of learning. More studies are needed to identify the specific conditions, situations and activities that enable and promote (or conversely: frustrate and undermine) such improvisational approaches. This missing part has important bearing and promise for questions around the organization, teaching and evaluation of broad studio- and practice-based courses in HCI and design – questions that become all the more important as the field undergoes continuing changes in scale, orientation, and the social and disciplinary range of the learners we seek to engage. To better engage these questions, the following sections introduce three participatory empirical studies around improvisation-based learning encounters in the HCI, art, and music fields.

4 EMPIRICAL STUDY

In this section, we report findings from three participatory ethnographic studies of our own: an interdisciplinary 'Tech-Art-Theory (TAT)' course offered in spring 2013; a 'Music Improvisation Ensemble (MIE)' studio course in fall 2016; and a series of independent studies, 'Media Art Practice for HCI (MAP)' that ran from 2016 to 2018 at Cornell University, Ithaca, NY. In these studies, various pedagogical activities based on the nature of improvisational learning (reflective, materially-driven, error-engaged, transgressive, and collaborative) were deployed as methods of teaching and learning. The main goal of these efforts was to study the specific conditions and activities enabling and supporting (or conversely: challenging and undermining) improvisational learning and teaching, with an eye towards lessons for CSCW and HCI.

For the TAT class, our research team collaborated with Daren Kendall, an instructor in the fine art department to design and teach an interdisciplinary course for six students. The key motivation of this course was to connect the different cultures and approaches of computer

engineering, art, and Science and Technology Studies (STS) in an open-ended and small group context. For the MIE course, the first author participated as student participant and ethnographer in a previously scheduled class led by Annie Lewandowski, a faculty member in the music department to study improvisational techniques in the teaching of experimental music. For the MAP case, we developed a series of independent studies based on lessons acquired from the TAT and MIE cases in which students could explore and build HCI-related knowledge and creativity through their own art and improvisational practices.

To study these empirical cases, our research team applied two general ethnographic approaches. One was in-depth interviews [34,119]. All teachers and most participating students regularly (either weekly or bi-weekly) sat for semi-structured interviews about their work processes, results and experiences of the classes. Each interview lasted approximately 30 – 60 minutes. In addition, our research team actively employed participatory observation combined with video ethnography to document and analyze participant behaviors in specific pedagogical settings and situations [69,85]. We also captured processes of learning and teaching processes in collaborative encounters ranging from group discussions and critique sessions to presentations and/or performances of student work.

All videos were recorded with the participants' consent, and selectively transcribed, coded, and analyzed by our research team, according to their relevance to the practices of what we would later come to identify as improvisational learning. While these processes followed an inductive and open-ended process built around the general precepts of grounded theory [17,111], the general focus of the research team fell within the following four categories: (a) how improvisational techniques were built into class structures and setups; (b) how such improvisational techniques were experienced by teachers and students; (c) what advantages and opportunities arose from improvisational techniques; and (d) what difficulties and problems emerged from improvisation, and how did these challenge the process of teaching and learning. The following subsections explain these themes and report findings and results from our three cases.

4.1 Tech-Art-Theory, Spring 2013

Tech-Art-Theory was a small experimental HCI course designed and taught by the co-authors together with a third collaborator, sculptor Daren Kendall [63] during spring 2013. Inspired by Barthes's insight[1] [5] on the nature of interdisciplinary study, the main theme of this class was to promote exploration and discovery in a mediated space organized at the intersection of engineering (tech), aesthetic (art), and social theoretical (theory) inquiry. Five undergraduates and one graduate student in the information science and fine art departments, recruited through an email course advertisement, participated in the class. These participants – three males and three females – were between 20 to 23 years of age. In addition to the in-depth interview studies, students' self-reflection studies describing the processes and results of individual class exercises and assignments were also analyzed. The class ran every Thursday evening for three hours over 16 weeks, with locations alternating between seminar rooms and studio spaces around campus, including woodshops, foundries, and laser-cutting rooms, mixing text and discussion-based with studio-centered modes of pedagogy (Figure 1). Material techniques and equipment engaged

[1] "Interdisciplinary studies… do not merely confront already constituted disciplines… it is not enough to take a 'subject' (a theme) and to arrange two or three sciences around it. Interdisciplinary study consists in creating a new object that belongs to no one"

through the course included welding, cement molding, woodworking, laser cutting, Arduino and other DIY design tools.

Fig. 1. Various learning spaces in Tech-Art-Theory class, Spring 2013

The class was divided into three roughly equivalent and overlapping components. The 'Tech' section, led by the first author, introduced basic and intermediate levels of Arduino, Processing, and other computational skills. The 'Art' section, led by Kendall, spanned activities ranging from welding and plaster molding to DIY tools and digital fabrication techniques. In the 'Theory' section, led by the second author, participants discussed theories and approaches drawn from the more conceptual ends of the HCI, design, and Science and Technology Studies (STS) fields. In each class at least two of the three elements were included, usually divided into roughly equivalent segments of 1.5 hours each. Instructors participated fully in each section, including those led by others.

Two main assignments were designed through the collaboration of the teachers to emphasize improvisation's 'materially-driven' and 'error-engaged' ways of learning in the context of HCI. In one assignment, 'Improvisational Technology', students were asked to produce technological objects in more intuitive and artistic ways by mixing both technological and artistic materials that the class had introduced. Like 'technology bricolage' [116] or 'Zombie Media' [45], the goal of this assignment was to mix, collage, or repurpose the artistic and technological materials that they had learned through the class rather than 'designing' them in linear and engineering fashions. The instructors further specified that results were not required to have functions or concepts. In subsequent group presentations, students brought a range of tangible artifacts that performed simple activities (like moving, blinking, or making sound) by employing technical and art materials and skills learned from the class. For example, one student designed an Arduino-based artifact called the 'Nothing Wrong Car (fig. 2)', which went back and forth with flashing LEDs and beeping buzzers, to express his idea that there was nothing wrong with a car that had no specific destination or utilitarian function.

In another assignment, 'Cross-media Conversation', students were asked to build a physical or visual thing that responded to a theoretical idea explored in the course (or as the prompt described, to "answer words with things") to promote more interdisciplinary and multi-sensory ways of learning. For this assignment, the students presented DIY objects, screen-based works, and drawings that reflected, sometimes obliquely, the ideas of their chosen theory, and briefly explained their rationales and relevance. For example, two students collaborated to produce "Unknown Mirror (fig. 2)", an interactive two-way mirror that produced animated LED patterns only when the audience was not looking into the mirror. They explained the work as partly inspired by ideas around the 'withdrawing' nature of objects presented in one of the course readings, Ian Bogost's Alien Phenomenology [10]. To support reflective and collaborative modes of learning, class exhibitions of work in progress were organized in which students and teachers shared ideas and feedback.

Fig. 2. Nothing Wrong Car (left), Unknown Mirror (right), Spring 2013

In later interviews, participating students reported a range of motivations to attend the class. Many of them related to the unusually integrative and interdisciplinary combination of course components, leading to expectations of "unique" and "more creative" learning experience. As a senior from the art department explained:

> "I like to bring the knowledge and information I learn from other fields that are seemingly unrelated to art and tried to pull them into art and express some aspect of that world through the language of art. I think that the more sort of disparate the two fields are the more interesting the collaboration in the end."

Most students (5/6) called out the learning opportunities in "Improvisational Technology" and "Cross-media Conversation" and their crucial grounding of ideas in the materially-driven approaches of the class. As one junior double majoring in information science and art described:

> "I guess making things makes me more comfortable with whatever I'm working with…I think it's more of a source of inspiration maybe, but I don't think I can actually go on from that unless I make something. So, I think making something helps formulate my thoughts more than it does the other way around."

The participants reported both positively and negatively on the general structure of the class. Some (4/6) described the learning opportunities attached to the various backgrounds in the class, and the positive "synergies" emerging from cross-disciplinary engagement. Others (2/6) described concerns – for example, that the "theory was too hardcore", "the syllabus has not made it easy to

keep up" or that the combination of activities felt chaotic or "inefficient." The most negative evaluation on this score came from a senior art student, who wrote:

> "So, let me be clear in my own feelings. This course is disorganized, meandering, prioritized completely ineffectively… and clearly there is no consensus or prior planning between said professors."

These challenges were echoed in feedback from instructors themselves, who reported the teaching experience as an "interesting experiment", but acknowledged that the emergent and transitional structure represented a distinct practical challenge to course planning and collaborative teaching. As one noted:

> "Our biggest challenge was mixing three different things in one place without much agreement [between the teachers] or experience on what we were actually going to teach. Other things, like preparing materials, tools and getting permissions from the school, were also headaches in preparing the class."

Through this teaching experience, we studied how the different topics and approaches of engineering, art, and STS could be integrated in a single HCI classroom. We suggested various improvisational activities in which students could develop their own projects at the intersection of technology making, aesthetic exploration, and theoretical study. The two main assignments ("Improvisational Technology", "Cross-media Conversation") and class exhibitions were designed to support reflective, materially-driven, and interdisciplinary ways of learning. To enable such learning, and to be responsive to the emergent interests of the students, the instructors often needed to organize various spaces, tools, and materials without much preparation time, a feature later reported as a core logistical challenge of the class. Four of the student participants reported such learning approaches as fresh and novel, and generally helpful in exploring and formulating more creative and interdisciplinary ideas and skills. Two however reported a mixed or more negative evaluation, arguing that the emergent structures were confusing and inefficient and expressing a preference for a more solid and indeed traditional plan for the course.

4.2 Music Improvisational Ensemble, Fall 2016

After this first experience, our research team decided to gain more specific skills and techniques in improvisational teaching from fields in which such methodologies play a more central role. To do so, we conducted a participatory study of a 'Music Improvisation Ensemble' class offered in our university's music department during the fall semester of 2016. This intermediate level course was dedicated to exploring "the elements of music from an improviser's perspective." The class was taught by Annie Lewandowski, a multi-instrumental musician exploring improvisational beauty in experimental and indie rock music [70]. In the course ensemble, she mainly used a musical instrument called 'Blister [19,84]', a DIY synthesizer that produces unpredictable and chaotic sounds by detecting the natural electric flow of the user's finger touch to the interface. The eight students involved in the course played musical instruments that included grand piano, electric guitar, bass, cedar thumb piano, and other DIY synthesizers. Musical backgrounds and proficiencies of the students varied from hip-hop to classical and from amateur to professional. Participants – five males and 3 females – were between 20 and 40 years of age.

Although open to any level of musician playing any instrument, an individual audition was required of all students. In the first author's own audition (in which he played harmonica), the instructor explained that this was not so much about evaluating musical proficiency, but was

meant more as "a means of introduction" to each other through sound-mediated conversation. To that end, she briefly asked the author to introduce himself by describing his interests, motivations, background and previous ensemble experience. After that, he was asked to play along with the instructor's Blister for 2-3 minutes without any prearranged structure. In a later interview, she explained that the first improvisation with prospective students in the rehearsal helped her understand their own musical languages, and organize the upcoming ensemble in more detailed ways. As she described:

> "There's a certain sort of 'getting to know you through sound' in the first time people improvise together. People throw an idea up there then they throw another idea back, so you get to know the person's musical language."

Starting from this rehearsal, the class introduced a range of concepts and practical methods by which multiple people, from duos to full ensembles, could produce collaborative music in improvisational ways. A key idea highlighted and continuously returned to throughout the course was that effective improvisation was neither random nor fully 'free,' but heavily based on the participant's "listening" activity, by which distinct and singular styles or "vocabularies" were brought into relation with one another. As the instructor described:

> "I find that students do come into the class thinking that they're just going to do whatever they want or that they can just play whatever. Actually, most of the class is about learning how to listen, and then developing some vocabulary so that you can feel that you're actively listening."

Like the earlier exercise of 'answering words with things' in the TAT sessions, this class also offered various in-class activities in which students were required to respond to visual factors, like video animation or human dance, with intuitive musical expressions. One session for example involved developing individual and group musical expressions in response to an invited Indonesian dancer's gestures. In another, the class discussed and practiced how the process of a flower blossoming in the atonic time-lapse film, 'The Birth of A Flower [110]' could be sonified and mapped to diverse musical expressions (fig. 3).

Fig. 3. Group Improvisation with 'The Birth of a Flower', Fall 2016

In addition, the instructor highlighted the speculative presence and function of "cross-language" practices between different musical genres, which allowed her and the participants to explore surprising creativities and instances of group emergence across differences. As she described:

> "There's this other plane of communication that I find I can't really nail down... It's amazing to find someone who is a bluegrass musician playing with someone who does grateful dead jam music and try to find this language. It's like something happened with these two people who don't even know each other necessarily."

Throughout the course, the instructor also highlighted the importance of rules and structures in both individual and ensemble forms of improvisation. She explained that certain pre-assigned limits and structures that pushed against the natural styles and intuitions of the participants were not meant to disrupt or remove musicians' free expressions. Instead, a certain level of constraint or pushback – even if seemingly arbitrary in nature – helped improvisational learners to engage in more cogent, coherent and unpremeditated forms of performance, while preventing the music from becoming "lost". As she described:

> "The class is always structured in that we'll start with some activity. Then there will be opportunities for a free improvisation, but it's coming out of some limitation. If you're not pushing against something, people get so lost and the music just gets nonsensical."

To this end, the course used diverse musical and non-musical factors, such as varied key signatures, tempos, visual cues, timbres, and sequences, as both individual and mixed structures. These structures were usually suggested by the instructor at the beginning of each section, and were reconstructed through the class collaboration based on group discussion and mutual listening practices. Structures achieved through this process had clearly and mutually agreed upon rules, but also considerable space and time in which individual participants could develop their own distinct and preferred musical forms. For example, the structure used for the final performance involved a combination of key signature, sequenced participation, and other minor rules. Within the structures, the participants were also required to develop their improvisational and creative musical expression in collaboration with others in the group. This is seen for example in the interaction below (transcribed from video analysis, fig. 4):

> On 16th November 2016, a day before the final performance, the eight participating students and the instructor gather for the final rehearsal. All participants are sitting in the chairs on the stage tuning their own musical instruments. These include two grand pianos, one electric guitar, one electric bass guitar, violin, saxophone, harmonica, and DIY synthesizer. There is no prepared score for the performance, and the participants in the moment have no clue what they will play for the performance. Once all participants are ready, the instructor stands up, asks them to stop warming up, and reminds them of the structure of the performance that the class members had produced collaboratively over the course.
>
> "Okay, so let's do this. So, each of you gets two entrances. It's all we've played. You can come in and play duo for a while, but ultimately, you're going to take over somebody else's solo, okay? You get two times to do it over the course of the improvisation. Plenty of time to do it. So don't feel like you're in a rush to jump in for your own part."

Throughout the course, the instructor reminded students that such an "ironic" musical space, wherein group structure and individual freedom both co-existed and collided with each other, was the engine that drove improvisation's distinct beauty and forms of group discovery. In later video analysis of the final performance, which ran ultimately for 18 minutes, we found that this structure often broke where more than two participants were engaged (sometimes up to four) in the play, which created its own situated and unique group-level expressions characterized by indeterminate mixtures of free play and fixed structure. For example, at around 16 minutes, four

players (harmonica, piano, electric guitar, and saxophone) came in and played together for 2 minutes. This moment naturally became the climax of the show as it was the loudest and the most collaborative musical expression.

Fig. 4. Rehearsal for the final MIE performance, Fall 2016

In this empirical study, we studied how the MIE class employed improvisation and experimental collaboration as a mode of learning and teaching. Reflecting theories of improvisation previously explored, the class highlighted the tension between pre-established structures and individual freedoms as a core catalyst of improvisational learning and discovery. To successfully turn such tensions into effective forms of group creativity and collaboration, the instructor highlighted mutual listening practices through which an initial pattern set by a leader or initiator was changed and evolved through iterative and open-ended musical 'conversations'. Pedagogically, we found that the entrance interview with prospective students employed in the class helped both teachers and students build mutual understandings of the topics but also basic aims of the class, especially when these were subjective or interpretive. In addition, crossover and multi-sensory practices, like experimental jam sessions between two musicians from radically different genres, or mapping flower openings to musical expression, were shown to be useful models for improvisational learning. Providing clear and mutually agreed upon structures was also found to enable students in developing intuitive and free forms of expression in more cogent and collaborative ways.

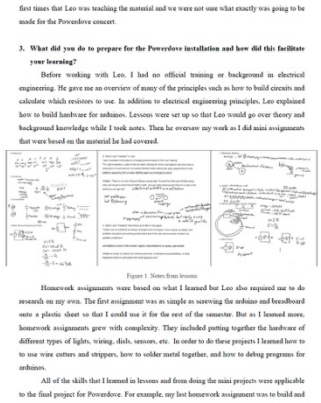
4.3 Media Art Practice for HCI, 2014 - 2018

Our third empirical study involved six cases of an ongoing independent study class titled "Media Art Practice for HCI" running from 2016 to 2018. Four undergraduate and two master's level information science students participated, recruited through course advertisement within the department. These participants – three males and three females – were between 20 to 24 years of age. Sessions ran once a week for 2-3 hours through 16 weeks in the authors' research lab where a round table, white board, and basic DIY electrical engineering tools and craft materials were

prepared. Students were given independent study credit for participation. The course syllabus was designed by both of the authors; however, it was the first author who met and worked with the individual students on an ongoing (and mostly one-on-one) basis.

Inspired by the MIE's entrance audition, the class required each student to give a pre-requisite interview (20 – 30 minutes) at the beginning of the semester in which the instructor learned their general motivation and background. According to students' existing proficiencies and academic backgrounds, some parts of the original syllabus deployed in the Tech-Art-Theory course were resurrected and edited. This tailoring was oriented both to pre-existing strengths and weaknesses, and the particular interests of the student participants. For example, for a masters student already proficient in technology building, the authors added more STS topics and artistic activities. For an undergraduate who was an avid songwriter, sections were added on data sonification, music visualization, and computational interfaces. Since the practice of "cross-media conversation" was found to be a successful improvisational practice in both the TAT and MIE cases, this course also employed it as a core learning activity in which students experimented with how their work could be converted or translated into different senses and media (for example, photography to poem, theory to dance, or data to sound).

Compared to the first Tech-Art-Theory experiment, this series of independent studies provided a much clearer structure of instructor guidance and expectations of student work. But it also offered more improvisational opportunities for both students and instructor. The class began by declaring several rules that all participants needed to follow, including: (a) that all participants were required to spend a minimum of three but not exceeding five hours on the class each week (including formal instruction time); (b) that each student was required to meet the instructor for thirty minutes each week to report and discuss their learning and progress; (c) that the instructor was engaged in all class projects, providing formative and iterative feedback as projects developed; and (d) that all participants were required to produce a specific socio-material form of reflection, called a 'dialogic learning portfolio', which combined the approaches and advantages of dialogic reflection [51,122] and learning portfolios [105,124]. For this reflection study, the students were asked to choose one of their friends (e.g. classmate, colleague) as an interviewer, asking questions about the learning processes, results and general experience of the class. By using this interview result as a guideline, the students were then asked to produce a learning portfolio (10-15 pages, fig. 5) in which they exhibited their raw, intermediate and finished artifacts alongside their reflective texts.


first times that Leo was teaching the material and we were not sure what exactly was going to be made for the Powerdove concert.

3. What did you do to prepare for the Powerdove installation and how did this facilitate your learning?

Before working with Leo, I had no official training or background in electrical engineering. He gave me an overview of many of the principles such as how to build circuits and calculate which resistors to use. In addition to electrical engineering principles, Leo explained how to build hardware for arduinos. Lessons were set up so that Leo would go over theory and background knowledge while I took notes. Then he oversaw my work as I did mini assignments that were based on the material he had covered.

Figure 1. Notes from lessons

Homework assignments were based on what I learned but Leo also required me to do research on my own. The first assignment was as simple as screwing the arduino and breadboard onto a plastic sheet so that I could use it for the rest of the semester. But as I learned more, homework assignments grew with complexity. They included putting together the hardware of different types of lights, wiring, dials, sensors, etc. In order to do these projects I learned how to to use wire cutters and strippers, how to solder metal together, and how to debug programs for arduinos.

All of the skills that I learned in lessons and from doing the mini projects were applicable to the final project for Powerdove. For example, my last homework assignment was to build and

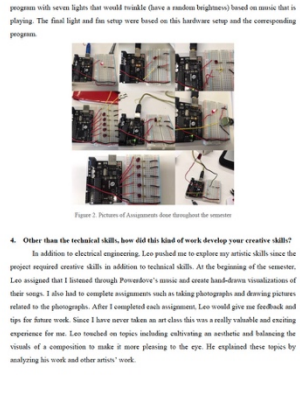

program with seven lights that would twinkle (have a random brightness) based on music that is playing. The final light and fan setup were based on this hardware setup and the corresponding program.

Figure 2. Pictures of Assignments done throughout the semester

4. Other than the technical skills, how did this kind of work develop your creative skills?

In addition to electrical engineering, Leo pushed me to explore my artistic skills since the project required creative skills in addition to technical skills. At the beginning of the semester, Leo assigned that I listened through Powerdove's music and create hand-drawn visualizations of their songs. I also had to complete assignments such as taking photographs and drawing pictures related to the photographs. After I completed each assignment, Leo would give me feedback and tips for future work. Since I have never taken an art class this was a really valuable and exciting experience for me. Leo touched on topics including cultivating an aesthetic and balancing the visuals of a composition to make it more pleasing to the eye. He explained these topics by analyzing his work and other artists' work.

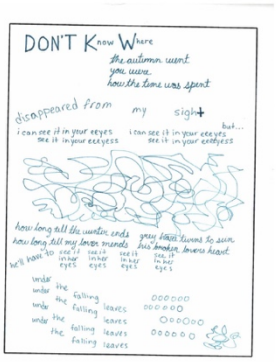


Figure 5. Visual representation of "Seeing It" by Powerdove

Fig. 5. One sophomore student's learning portfolio, Fall 2016

Beyond this structure, students were given considerable freedom, and encouraged to develop their own creative projects working in media ranging from web interfaces to music, dance, photography and new media art. Throughout the course, the instructor explained the basic motivation and expectation behind such pedagogy by introducing various theories of improvisational learning, and continuously reminding the students that this mode of learning required ongoing, deliberate and iterative reflection.

For sixteen weeks, this course consisted of fifteen in-class learning and making sessions, with approximately half (5 – 7, depending on the semester) assigned as 'open topic' sessions, which covered emerging topics and practices that the instructor improvised through weekly interactions with the students. Topics were communicated to the students at least one week in advance. These open sessions sometimes involved HCI related topics such as web API, Arduino, or relevant HCI, art, and social science theories such as critical and speculative design, computational aesthetics, and post-humanism. In other cases, they involved seemingly unrelated topics and activities like synesthesia, photojournalism or art-video watching, selected according to interests and interactions uncovered in the entry interviews with students and/or earlier class sessions.

The students produced a range of work for the class projects. These included web interfaces, tangible devices, music, dance videos, and photo essays, all of which were required to draw on technologies or theories learned from the course. For example, one masters student created a web interface titled 'Life Symphony (fig. 6)', in which a user can produce MIDI-based symphonic music based on global live birth and death data gathered from the CIA World Factbook's API. Another masters student produced a hardware project called 'invisible smile' in which a user can produce an invisible image of a smile icon on the installed screen, which only can be seen in "technology's eyes" (thermal camera), by applying heat to the resistors through cranking an electrical generator.

Fig. 6. Life Symphony, Fall 2017

Other students produced less technological projects where they employed their own creative practices (like music or dance) as main features of the work along with what they conceptually learned from the class. For example, one junior student choreographed and performed dance sequences in which she explored how she might reconsider everyday technological objects, like chairs and light bulbs, as equal dance partners by interacting with their material and functional properties (fig. 7).

Fig. 7. Technology as a Dance Partner, Summer 2018

In the later interview and reflection studies, the participating students reported various motivations to take the course. These included "to combine engineering knowledge with my artistic passion", "to get my hands dirty on this Arduino stuff", and "to be able to critique art." About the pre-assigned rules and structures of this course, the students reported both positive and challenging aspects. Some students (3/6) questioned the effectiveness of the 3-5 hour limit, reporting that this "did not work well because of the nature of the work." One masters student admitted that:

> "I never consciously restricted myself to working a certain number of hours…I mean, for me, it's more important to complete the work than restrict myself to time. And maybe these things were kind of interesting, and so it didn't mean that I stopped there. Had it been boring, probably I would have restricted myself."

On the other hand, other students (3/6) mentioned that the limitation of time gave them a kind of intellectual pressure and "urgency" that ultimately helped them work in more productive ways. As one student explained:

> "The urgency definitely maintains a sense of inspiration and keeps me on my feet. If I had more time than I needed, then I would not appreciate the time spent on my creative work as much as I do."

In terms of the emergent character of the course structure, students showed both neutral and positive stances, but rarely mentioned the concerns around confusion or (in)efficiency ascribed by some to the earlier Tech-Art-Theory experiment. As one reported:

> "I feel like I didn't mind the fact that it wasn't fully planned. But that's probably just a personal preference. Also, I feel like because I'm so busy in my other classes during certain periods in the semester, I don't really realize how the time has progressed. I just take the classes week by week."

Another reported that she especially enjoyed the emergent and studio-based mode of the class:

> "You didn't try to be like, 'Oh you have to follow step one, two, three, four, five, in order to achieve this.' But it's kind of like we build up the structure of the course over individual meetings, through weekly creations. Like, 'Okay, this week I will make this.' Then the next direction you think should be that."

On the other hand, one junior expressed disappointment that the open-ended learning process did not result in the Arduino-based tangible musical instrument that she had expected to produce for her final project. As she mentioned:

> "However, due to the shortage of time, [instructor] and I decided that it would not be feasible. I was slightly disappointed that I didn't get to make something physical with this independent study that would also relate to my musical interests."

The instructor also reported ambivalent feelings (described as both "exciting" and "challenging") around the open topic structure of the class. On one hand, prepping on the fly for an emergent range of topics required extra time and effort on the part of both teachers and learners. But this also provided a prod and collaborative opportunity to learn from each other and teach new things interdependently. As one instructor described:

> "I think improvisational pedagogy basically makes both teacher and student more engaged in the class. I think it was a kind of collaboration and mutually educational work. The teacher also has to learn from students and study something new continuously. It sounds like extra work for the teacher, but indeed I found that it gave me much more motivation and excitement."

In this section, we reported the experience of a series of semi-structured independent studies that sought to incorporate student improvisation and more art-centered modes of learning in the context of HCI instruction. Compared to the Tech-Art-Theory course, these studies started with a more articulated set of rules and structures, albeit with considerable space for free practice for students. Entrance interviews and weekly meetings were employed as a means of 'mutual listening' between teacher and student to plan indeterminate parts of the class. Participants reported that these improvisational approaches combining structure, communication, and open-endedness contributed positively to their motivation, engagement and experience. More images and videos of the students' works can be found in this project website (https://www.cornellhci.org/TAT).

5 DISCUSSION

The above sections explored the nature of improvisational learning and teaching through theoretical analysis and three ethnographic case studies. From this integrated work, this section reports specific pedagogical conditions (*socio-material evaluations*, *multi-sensory practices*, and *making safe spaces for error*) that can support improvisational learning. Finally, we speak to three problems of HCI pedagogy – *relevance*, *assessment*, and *inclusion* – that improvisational methods can help to address.

5.1 Supporting Improvisational Learning

5.1.1 Socio-material Evaluations

Our study first shows how improvisational learning may be driven by iterative reflection on both social and material actors in the situation. As the ideas of "learning by doing" in pragmatism and "wicked problems" in research through design explain, much of what is to be learned, achieved or solved in improvisation cannot be pre-assigned, but is "situated" and emerges through a learner's interdependent interaction with both human and non-human actors. These collaborative actors can range from classmates and teachers to technological objects themselves – for example, the thermal camera and metal-framed chair in the cases above. Developing such situated ways of learning, various researchers and educators have underscored the crucial social

and material dimensions of critical reflection, which enabled them to explore the specificity and richness of learning beyond the abstract or conceptual levels.

As a way to support such socio-material learning process, our teaching team developed 'dialogic learning portfolios' that integrated the approaches of dialogic reflection [51] and learning portfolios [124] as a key tool and mechanism for the assessment of learning outcomes. Unlike other showcase and assessment portfolios, learning portfolios focus on the process of learning and self-reflection by composing and presenting the learner's raw, intermediate, and unpolished works [105]. As Bardzell et al 's 'multi-media documentation' [3] and Gaver & Bower's 'annotated portfolio' [36] similarly point out, such curated forms of materials, including computational artifacts used and produced from one's own learning process, can play a role in the generation of insight and knowledge, both for those who encounter them and those who design them. In addition, as proponents of 'dialogic learning' explain, one's learning experience can be more effectively articulated through in-depth presentation and conversations with others (e.g. peer interviews) than through other purely descriptive and individual modes of reflection [21,22,122]. As Dewey, Schön, Ratto, and the student quoted earlier all emphasize ("it makes me think about what I make, and why I make"), such mixed forms of reflection can help students connect the doing, making, and knowing elements of their own practice, while extending their distinct perspectives and creativity in collaboration with others.

5.1.2 Multi-sensory Practices

Our study also shows that improvisational learning and creativity may involve multisensory learning [16,109] and reflective conversation [103] across different types of media. Compared to more linear learning models where learners engage content in step-by-step and single sensory modes (like learning Arduino by reading an instruction manual), improvisational learning involves the integration of learner's visual, auditory, kinesthetic, and tactile experience (i.e. seeing, hearing, doing, and touching) and may be supported by crossover conversations between a variety of situated media and languages [97].

As revealed in the process of making in the 'Unknown Mirror' and 'Life Symphony' projects, technological artifacts can be designed not only by engineering and utilitarian concerns, but also by other aesthetic considerations (e.g. visual, musical, or conceptual). To support such multisensory forms of learning and creativity, practices of 'cross-media conversation', like converting Bogost's text to interactive technology, expressing sound while watching a flower blossom, or studying birth and death API data through audio-visual practices, were employed in our study. Although such cross-media practices occasionally led to unclear, incoherent, and provisional results, their translational processes helped learners engage in unique and more heterogeneous forms of creativity that extended beyond what could be achieved by other more linear and isolated learning models.

5.1.3 Making Safe Spaces for Error

Finally, our study explains that improvisational pedagogy needs to offer spaces that allow and support learners situated mistakes and transgressive expressions. Whether in art studio, dance rehearsal hall, or the confines of a musical practice room "making a space safe for stupidity" [64], in which fumbling and "messy" experimental practices can lead to novel and unanticipated forms of creativity, is a core condition of improvisational learning. For HCI, this may mean providing more flexible learning spaces in which learners can explore emergent and non-linear modes of practice without excessive adherence to pre-defined goals (or undue threat of the consequences of 'failure'). However, as Vygotsky's gaps, Sawyer's "artful balance between structure and

improvisation", and the MIE class structure incorporating arbitrary constraints suggests, providing learners a certain level of constraint or oppressive structure can also promote learning motivation, engagement, and discovery. In other words, creativity in improvisational situations may benefit from neither a fully determined plan nor an entirely open field action (put simply, 'just letting learners do whatever they want'), but emerges instead as a negotiated space in which learners struggle, fail, and arbitrate their freedom within and against the exigencies of existing rule and structure.

Our study suggests that building such safe spaces for error requires a collaborative process between teachers and learners that itself blurs the line between teacher and student. As one teacher in our empirical study explained in describing his teaching experience as "mutually educated work", teaching and learning in improvisational settings are neither clearly separable nor independent activities. Instead, they exist in an interdependent relationship wherein teachers and students engage in "collaborative tension" to produce a mutually educative, but sometimes challenging, experience in which both sides must give and take. To manage such tensions, mutual listening activities can make the pedagogical process less risky and more reciprocal. As the examples of pre-requisite auditions, weekly meetings, and open topics in our study suggest, such collective improvisational spaces built on mutual communication may help both learner and teacher to expect, manage, and control upcoming uncertainties and conflicts, and ultimately to produce a vocabulary or language of their own in relationship with each other.

5.2 Problems of HCI Pedagogy

The above analysis of improvisational learning has underlined the value of learner-driven and artistic practices in the broader science and engineering fields, along with the hybrid disciplinary fields that constitute the study of HCI and design. Beyond the particular sites explored here, how do improvisational methods help us to address known problems in HCI pedagogy?

Relevance: Improvisational methods may help speak to *problems of relevance* in HCI and broad engineering pedagogy, where 'what to learn and teach now' may not be correspond to "how the world is now" [2] and the learners' real and present social life [24]. Especially in specific lecture-based HCI classrooms focusing on classical STEM subjects (data structures, linear algebra, etc.), learners' interventions to the subject matters are usually limited or prohibited. In such educational environments, building some amount of open spaces into syllabi – in which the topics of individual sessions are left for later decision according to the evolving interests of the class – can help reduce such problems of relevance. Like the open-topic model in our experimental pedagogy, such co-constructive and participatory opportunities for learners to define their own subject matter can help them attend to and develop more personally motivated inquiries and creativity in the context of other topics in the class. Similarly, the addition of improvisational practices of technology design, like 'improvisational technology' or 'technology bricolage' [116], can be a great way to promote learners' constructive and self-defined inquiry practice. Presenting this work publicly and understanding their values and problems through other social members' interaction and critiques can also help learners develop more interdependent creativity and knowledge relevant to the learners' present lives and circumstances.

Assessment: Improvisational methods may also speak to *problems of assessment,* pointing out that many forms of HCI learning, especially those which are driven by improvisational methods, are difficult to evaluate through classic approaches to assessment (e.g. letter grading by comparing one to another). As the perspectives of constructivism and pragmatism highlight, human learning processes are intrinsically 'reconstructive', with no clear boundary between the starting and end points of learning – thus, no right and wrong, or better and worse learning experience as arrayed

on some universal and invariant plain. Although such evolutionary ways of learning have advantages as discussed above, they may discourage some HCI learners and teachers by challenging senses of comfort and predictability – especially amongst those unfamiliar with studio- and experientially-based methods of inquiry. Thus, for more studio-based and hybrid HCI classes where some part of what is to be learned is arrived at through emergent and open-ended processes, establishing appropriate and clear pedagogical structures, like deadlines, deliverables, and clear (if flexibly implemented) evaluation criteria, may help establish a frame or constitutive tension against which learners' free activity can unfold. As our discussion of mutual listening suggests, such pedagogical structures can be collaboratively constructed through pre-assigned communication spaces to establish safer and mutually accountable classrooms.

Inclusion: Finally, improvisational methods may help to address *problems of inclusion*, providing diverse opportunities for learners and contexts less well-served by existing traditions of teaching and learning. For example, improvisational methods can be an assistive model of pedagogy for those with particular non-linear learning styles or learning challenges. For learners with ADHD (attention deficit hyperactivity disorder) or ODD (oppositional defiance disorder) who may suffer under monotonic and unilateral modes of learning, or like the dancers, makers, photographers and musicians in our study who already have strongly motivated practices, improvisational learning can provide an alternative mode that allows access to certain subject matters in more flexible and self-defined ways. The multi-sensory learning and cross-media conversation examples described in our paper also can be supportive tools for those who have more complex neurological conditions (e.g. synesthesia, dyslexia) and "different kinds of minds" including those who might fall at various places on the spectrum [40,76]. Similar to practices of art therapy [115], improvisational methods may support psychological and cognitive expressions that can help learners develop self-awareness, self-esteem, emotional resilience and a sense of success and accomplishment within an educational environment that has more typically treated their difference as a lack or deficit.

It can also be beneficial for classrooms where cultural or language barriers exist. As it provides another plane of communication through making things and presenting them, improvisational techniques can soften language hierarchies or cultural barriers (whether recognized or invisible) that often lead to differential learning outcomes and experiences [57,121]. Such psychological, artistic, and cross-cultural learning engagements may help us to reimagine school as not only a "bank" of knowledge (in which not all currencies are traded equally) but also as a therapeutic encounter in which learners' natural curiosities, mistakes, and a never fully controllable outer world get all tangled up to produce more reciprocal and inclusive forms of creativity and knowledge.

5.3 Limitations and Future Work

However, improvisational pedagogy may face important limits and difficulties, especially within the constraints of a strictly institutionalized educational system. Whereas the topic and practice of what is to be taught and learned are subject to change in improvisational learning environments, the institutional and regulatory structures of the school system may lack the flexibility and suppleness to satisfy such contingent calls. Scale poses problems of its own: for larger enrollment classrooms where individual students' learning interests and styles are too diverse for teachers to follow and support in more individualized or artisanal ways, such improvisational and co-constructive pedagogical models may be challenging or overwhelming to practice. For teachers and learners more comfortable and motivated by grading systems built

around clear, universal, and easily articulable evaluation criteria, improvisational pedagogy can appear confusing, anxiety provoking, or arbitrary – a point which reinforces the importance of building and updating mutual and collaborative expectations before and throughout the class. Despite these efforts, the result for some may still feel, as it did for one participant quoted above, "disorganized, meandering, prioritized completely ineffectively… and [with] no consensus or prior planning between said professors." Improvisational learning and improvisational teaching are not for everyone.

6 CONCLUSION

Why is it important for HCI to adapt more improvisational learning and teaching techniques today? Uncertainty and the pace of change in rapidly evolving socio-technical environments may benefit from more nimble, responsive and improvisational forms of education [18]. At the same time, as existing and emerging tools and learning platforms from printed books to online education to virtual reality become available to learners, the activity of learning itself may naturally evolve towards more autonomous and complex forms, and (further) away from static and passive conceptions. By making connections between different approaches across traditionally separated disciplines, learners may learn to build their *own* learning methods vis-à-vis the existing task and act of learning. In addition, growing awareness of the deep and pernicious links between inequality, artificial intelligence and computing more generally, demands more careful social and intercultural considerations in the learning, teaching, and development of computational and engineering systems [91]. For the fields of CSCW and HCI, where a wide range of academic cultures continuously meet, merge, and collide, improvisational forms of pedagogy can also support a more negotiated and open space of encounter in which people from different disciplines, styles of learning, and orientation to the world can work together to build more reciprocal and collaborative forms of creativity, discovery and learning.

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