SUPPORTING PARTICIPATION THROUGH LIVE MEDIA

A Dissertation

by

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ABSTRACT

Throughout the past century, live media has grown to play a significant role in how we experience the world. Live media connects people in real-time with events happening around the world and helps people establish shared social realities. Recent live forms enabled by the internet are shifting the paradigm away from just passively watching to actively participating. This has significant implications for how we engage in critical aspects of society, including education, politics, work, play, and everyday life. In this work, we focus on understanding emerging live media phenomena and designing new forms to support participation. We do this through two core approaches: qualitative investigations and live media probes.

To build an understanding of practice and communities, we conduct qualitative investigations of two situated live media contexts: the video game live streaming site Twitch and massive open online courses (MOOCs). Using Marshall McLuhan's concept of hot and cool media, we explore how live streaming as a medium affords building these online communities through participation in shared experiences.

Building on these findings, we design, deploy, and evaluate live media probes. These probes implement new forms of live media, with the goal of eliciting new forms of live experience and participation. We first design Rivulet, a live media probe supporting new participatory modalities and multiple simultaneous live streams. Through our investigation of Rivulet, we discover how, by incorporating new modalities, we can support higher-impact forms of participation in live experiences. Next, we design Collaborative Live Media Curation (CLMC), a new live media form enabling the collaborative real-time assemblage of web media including text, images, sketch, and live video and audio. We deploy LiveMâché, a CLMC probe, in four situated online learning contexts to support participatory learning activities. We find that CLMC supports new forms of real-time conversational grounding and participation. In conclusion, we summarize and discuss our findings and discuss future directions for live media research.

DEDICATION

To my wife, Sarah, for all of her love, support, and hope throughout this journey.

To my parents and grandparents, for everything they have done to support me.

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NOMENCLATURE

CLMC	Collaborative Live Media Curation
FFWC	Free-form Web Curation
LPP	Legitimate Peripheral Participation
MOOC	Massive Open Online Course
PTT	Push-To-Talk
TA	Teaching Assistant

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1. INTRODUCTION

Throughout the past century, live media has grown to play a significant role in how we experience the world. With the invention of the radio came our ability to listen to real-world events happening at a great distance. President Franklin Delano Roosevelt's fireside chats, broadcast on live radio, helped connect citizens of the United States during a time of great crisis. Later, the invention of live television let us see events, around the world, as they happened. Today, the internet has lead to a plethora of new live media platforms, such as Twitch, Periscope, Google Hangouts, and Facebook Live. These media forms are transforming how we experience reality and how we participate in society.

When we think of live media, the most obvious constant is that they transmit and reproduce a signal instantaneously, or at least nearly instantaneously. Indeed, this is how we define *synchronous media*. However, live tends to imply something more about how we experience media. Couldry notes that *liveness* implies connecting to real-world events as they happen [1]. He explains that liveness guarantees a potential to share social realities, in real time, across the world [1]. Early forms of live media connected people with broad centralized realities. People experienced presidential addresses, the Japanese peace treaty conference following WWII, and the early missions of United States space exploration via live media.

Recent live forms, primarily those enabled by the internet, shift the paradigm away from the centralized, toward the distributed and decentralized. Right now, I can go watch any of hundreds of thousands of live video streams of people playing games, eating food, driving, hanging out, or working. Further, these new forms are no longer unidirectional. We are no longer limited to passively listening to or watching a live broadcast. We can more actively participate in live experiences, by sending a like, a heart, or a chat message; or broadcasting our own live video. The focus of the present work is this shift in the paradigm of live media and live phenomena.

The ready availability of decentralized live media platforms is transforming how people engage with society. We see, with the emergence of Twitch, people are coming together, by the

millions, for exciting participatory game play experiences (Chapter 3). In online education, live media is connecting students around the world and giving them a more engaging way to learn in online course communities (Chapter 4). We are also starting to see that distributed live media is transforming how people engage in politics [2, 3] and activism [4, 5, 6, 7]. In the present research, we work toward building understanding of these relatively new phenomena, through qualitative investigation of emerging contexts.

In addition to the participatory live media forms that are driving these emerging phenomena, we work to design and evaluate new forms. We create novel combinations of live modalities to elicit new forms of experience and participation. We work to empower people through participation in these new modalities. Beyond static combinations, we work to design media spaces where participants can make their own combinations to create media places that support their activities.

The long term goal of this research is to investigate novel live media forms to support people's participation in critical aspects of society, including learning, politics, work, play, and everyday life. We do this through two core approaches. First, to build an understanding of live media practice and communities, we conduct qualitative investigation of situated social contexts that are already employing live media. We investigate two such contexts: the video game live streaming site Twitch as well as massive open online courses (MOOCs) using live media, which we call Live MOOCs. Second, building on our understanding of live media developed through qualitative investigation, we design, deploy, and evaluate live media probes. These probes implement new forms of live media, with the goal of supporting new forms of live experience and participation. We then deploy these probes in situated contexts to evoke new experiences and understandings of live media.

In this chapter, we start with a brief discussion of sensitizing concepts. We follow this with a discussion of our two main research approaches, i.e. understanding live media practices and designing and evaluating live media probes. Finally, we discuss the present work's research contributions.

1.1 Sensitizing Concepts

We introduce and discuss sensitizing concepts that we use to frame our research. These concepts are foundational. They motivate our understandings, designs, findings, and conclusions. We discuss concepts of participation, community, hot and cool media, space and place, and finally combining modalities to create new forms.

1.1.1 Participation

Participation is an aspect of collective action that we particularly focus on in this work. But, what is participation? According to the Oxford English Dictionary, participation is "the process or fact of sharing in an action, sentiment, etc." or "active involvement in a matter or event, especially one in which the outcome directly affects those taking part" [8]. We agree that participation is a process or act of involvement in an event, activity, or community. We can think of participation in terms of a singular contributing action. Alternatively, we can think of it as a holistic account of a person's involvement in a particular situated social context. We consider both of these aspects of participation throughout this work.

Participatory activity can take many different forms. Pretty et al. develop a typology of participation to describe the range of potential participatory activities and relationships that arise through people's engagement in projects or movements [9]. To illustrate, we present their taxonomy (from Preston [10]).

1. *Passive participation.* People participate by being told what is going to happen or what has already happened.

2. *Participation information gathering.* People participate by answering questions (i.e. through surveys). People do not have the opportunity to in influence proceedings.

3. *Participation by consultation.* External people listen to the views of local people. External professionals define both problems and solutions, and may modify these in light of people's responses.

4. *Participation for material incentives.* People participate by providing resources, for example labour, in return for food, cash or other material incentives. People have no stake in prolonging activities when the incentives end.

5. *Functional participation.* People participate by forming groups to meet pre-determined objectives related to a project. Such involvement tends to occur after major decisions have been made. These institutions tend to be dependent on external initiators and facilitators, but may become self-reliant.

6. *Interactive participation.* People participate in joint analysis, which leads to action plans and the formation of new local institutions or the strengthening of existing ones. Groups take over local decisions, and so people have a stake in maintaining structures or practices.

7. *Self-mobilization.* People participate by taking initiatives independent of external institutions to change systems. They develop contacts with external organizations for resources and technical advice they need, but retain control over how resources are used.

Through our work, we observe instances of these types of participation, as well as new forms. It is important to consider why participation matters. Putnam argues that developing social capital through participation in political, civic, and religious communities as well as informal associations, is a critical aspect of a democratic society [11]. He argues that, at the time of his writing, participation in these aspects of American society was in decline. He associates this trend, in particular, with the arrival of new mass media forms, e.g., television. He argues that television is an isolating modality that stifles individual participation, what McLuhan calls a *hot* medium (Section 1.1.3) [12]. This decline in participation is correlated with a myriad of negative outcomes, including reductions in child development, happiness, and economic prosperity, as well as an increase in violent crime [11]. One of the aims of the present research is to foster more individual and collective participation and the establishment of new communities through participatory live media.

Further, Lave and Wenger argue that participation is a critical aspect of social learning processes [13]. They introduce the concept of *legitimate peripheral participation* (LPP) to describe

social learning processes based on the master and apprentice learning paradigm. New learners engage in communities of practice through such legitimate peripheral participation. By 'legitimate', they mean activities that are necessary to a practice, but at its 'periphery'. An example describes how apprentice midwives engage in gathering medical supplies, passing messages, and running errands. Over time, new comers become old timers by transitioning to more core participatory roles. In the case of the midwife, she begins assisting in or performing her full duties during a delivery. Through such iterative participatory processes, learners not only acquire skills and knowledge, but, further, *situate* themselves in the social context of a community of practice [13].

While it is clear there are benefits to participation in society, Preston argues that there are also potential pitfalls [10]. She argues that, while participation seems attractive and inherently good, participation can be manipulative and used to support hegemony, i.e., the prevailing social and political order. Further, Rahnema argues that, while participation can empower and legitimize underrepresented peoples and ideologies, "no form of social interaction or participation can ever be meaningful and liberating, unless the participating individuals act as free and unbiased human beings" [14]. However, societies tend to develop "commonly accepted creeds (religions, ideologies, traditions, etc.) which, in turn, condition and help produce inwardly un-free and biased persons" [14]. This conforming trend can lead to counter productive or even harmful participatory movements. Rahnema cites how political participation has led to exceedingly destructive movements throughout history (i.e. in Germany, Russia, Cambodia, etc.) [14]. Putnam notes that communities characterized by bonding social capital, i.e. exclusive social relationships built on a homogeneous identity, while good for mobilizing solidarity can sometimes lead to destructive movements [11]. Indeed, in recent events, participation in isolated online communities has led to the emergence of disconcerting social and political movements [15, 16]. Thus, participation in and of itself is not always beneficial.

However, we can see how participation is a critical, empowering part of society, which has clear benefits. In this work, we explore how different media support participation in a variety of situated social contexts. We also design new media forms and evaluate their impact on participation. A long

term aim of this work is to be able to inform future media design and, through this, to strengthen participation in critical aspects of society.

1.1.2 Community

In our investigation of live media, we frequently consider online communities, which Resnick and Kraut define as "as any virtual space where people come together with others to converse, exchange information or other resources, learn, play, or just be with each other" [17]. While there is much work investigating online communities, we find it useful to provide a concrete discussion of the qualities of community. To do that, we rely on McMillan and Chavis's definition of *sense of community*, which they argue consists four components: membership, influence, fulfillment of needs, and emotional connection [18]. We use these as a basis for characterizing communities we encounter in our work.

The first component of sense of community is membership. McMillan and Chavis argue that the status of membership is developed through personal investment in the community, yielding feelings of the right to belong and community identity [18]. Membership serves as the primary boundary determining who is in and outside of the community. The primary form this investment takes in communities we examine is through members' spending their time and personal energy, i.e participating in the community's activities. Participants often also invest personal skills and money into online communities.

The next component, influence, is driven by two opposing human phenomena. People are attracted to groups whose activities they can impact [18]. We observe that in practice, people are attracted to live media communities where they are recognized by other participants and can impact the community through participation in activities. Communities also evoke a sense of conformity, members naturally adopt shared qualities inherent to the group. In practice, we find that online communities tends to exhibit a shared social atmosphere instituted by the community members.

A core part of members' sense of community is that communal benefits fulfill their needs in some way [18]. This fulfillment takes several forms, including emotional rewards such as sociability, the status of membership, and the success of the community. These rewards and their

importance to participants is evident in stream communities. Another common reward is the gaining of knowledge and skills available from other community members. In online education and video game communities, we observe that gaining knowledge and skills uniquely available through participation is a significant driving factor in their formation.

Finally, community members develop an emotional connection through shared history and an identification with other members. This shared connection is developed primarily through continued participation: "The more people interact, the more likely they are to become close" [18]. The more positive the experience that members have in the context of the community, the greater their emotional connection to that group. In our investigations of live media communities, we find that regulars and other community leaders take it upon themselves to engender positive experiences to build the community through encouraging participation and open acceptance of new members.

1.1.3 Hot & Cool Media

McLuhan introduces the concept of *hot* and *cool* media in order to discuss the relationship between media fidelity and participation [12]. McLuhan defines cool media as low fidelity media, which because of its low fidelity, is able to afford participation. In contrast, he defines hot media as high fidelity media that affords less participation. A higher fidelity media expresses a more complete message that saturates the senses and requires little interpretation.

As an example, McLuhan describes the photograph and film as hot media, because those modalities have high fidelity and little room for audience participation [12]. By way of contrast, he describes telephone as a cool medium. It is both lower fidelity and affords opportunity for people to participate through it [12]. He also describes the comic book as cool as it is lower fidelity, when compared to a photograph, and affords more cognitive participation on the part of the reader to fill in the details. McLuhan goes on to say "any hot medium allows of less participation than a cool one, as a lecture makes for less participation than a seminar, and a book for less than dialogue" [12].

In our interpretation, McLuhan describes these media with some sense of irony. While television and film were the "hot" media of the day during his writings, he saw that these media limited

broad participation and were controlled in a fairly centralized way. McLuhan died before the invention internet and many of the resulting changes in media that have taken place. Indeed, the internetworking of media both redefines the limitations of media and restructures how it is organized and controlled. We observe throughout this work that the internet has led to the emergence of more participatory forms. However, it also possible that modern internet media can also reinforce some of the prevailing centralizing tendencies of media.

In this work, we examine a number of modalities, combinations of modalities, and media forms. We use McLuhan's hot and cool concept to conceptualize and discuss the affordances of these. For example, live streaming video is hot in that is very high-fidelity, but streaming video does not afford much participation. In contrast, text chat is a very cool modality affording lots of participation, with much less fidelity. We use the concept of hot and cool media to discuss and conceptualize how combining modalities leads to new forms with new affordances. In turn, these new forms lead to the formation of new kinds of participatory online communities.

1.1.4 Space and Place

Tuan explores the relationship between the human experience of space and place [19]. He argues that space is an abstract concept describing the physical qualities of an environment. We experience space through our movement through it. Place however is more concrete to us. Place is manifested when we pause and observe the space around us, when we start to experience and understand it. Space becomes place as we endeavor to endow it with value [19].

Building on Tuan's description, Harrison and Dourish explore the relationship and differences between space and place, and how they apply to the design and understanding of media environments [20]. They note that a space encompasses the physical construction, arrangement, and properties of an environment. Meanwhile, a place exists in a space that has been adopted by a community or some group of people. Places are spaces that have been invested with value and have through this investment become imbued with understood social context and practices. Objects and features in places are assembled either mentally or physically to reflect the values and practices of the people who frequent them [20].

They argue that *placeness* is not something that can be designed, per se, by the creator of a space. Rather, placeness is a product of situated social activity that occurs in a space. While placeness cannot be designed, they argue that it, placeness, can be *designed for*. A space can be designed so that it may be easily rearranged and adapted, through use, in order to suit the needs of its occupants [20]. Our design of *Collaborative Live Media Curation* (CLMC), presented in Chapter 6, originates from this concept of establishing placeness through the assemblage and composition of space. CLMC is a new media space that affords the collaborative, free-form assemblage of media elements to meet the needs of participants. Ultimately, we aim to support the creation of live media places, i.e. media spaces incorporating live media that have been assembled to reflect the needs and values of a community.

Harrison and Dourish also present the concept of hybrid spaces, which, beyond virtual environments, include real physical space. They argue that media spaces, through the use of audio and video, connect different parts of the physical world to create hybrid spaces. We see, throughout our investigation of existing practice and new media prototypes, how media spaces connect and transform physical spaces in the real world.

1.1.5 Combining Modalities to Create New Media Forms

The combination of modalities to create new media forms is a recurring theme that runs throughout this research[1]. Twitch combines video games, live streaming video, and text chat. Live MOOCs combine live streaming video with YouTube videos and asynchronous discussion forums. Rivulet combines multiple lives streams with push-to-talk audio, hearts, and text chat. Finally, Collaborative Live Media Curation empowers participants to do their own combining to create media contexts that fit their needs.

This theme also recurs in prior media and art literature. McLuhan discusses how the combination and hybridization of media leads to the emergence of new forms [12]. He illustrates through

[1]We draw on Cohen's articulation of the terms media and modalities [21]. He uses the term "medium" to refer to the holistic "production, storage, and transmission by the machine of signals" [21]. Alternatively, he uses "modality" to "concentrate on the syntactic, semantic, and pragmatic properties of the signal" [21]. We use *medium* to refer to holistic tools (e.g live streaming or CLMC), while using *modality* to refer to specific communication channels (e.g. text chat or screenshares).

the example of how the movie has changed the novel and how the radio and television has changed the news story. These combinations not only bring together the social and cultural practices of combined media, but they lead to the emergence of new practices and affordances. He notes that "the hybrid or the meeting of two media is a moment of truth and revelation from which new form is born" [12].

Similarly, Higgins introduces the concept of intermedia, media forms that fall between currently accepted forms [22]. He describes Duchamp's found objects [23] as intermedia, as they fall somewhere between sculpture and something else. He highlights Kaprow's "happenings" [24] as an intermedium between "collage, music and the theater". Kerne, in his discussion of interface ecology, describes how interfaces mesh systems of representation [25, 26]. They have the potential to bring together and connect disparate ideas, economies, and people.

A core aim of this research is to examine, experiment with, and understand situated contexts involving live media combinations. How are these combinations leading to new forms? How do combinations leverage the affordances of prior forms? How do these hybrids bridge disparate personal, economic, and cultural contexts? What new qualities emerge through these hybrid forms? And what practices and new social contexts emerge around them?

While we consider a few isolated live media contexts, we have to remember there is an ever expanding global media ecosystem. Viewers on Twitch aren't just engaging through the text chat. They are watching YouTube videos, posting on Twitter, sharing on Facebook, and memeing on Reddit. People are engaging through their own combinations of media. While we can create new forms through contextualized combinations, there are far more complex associations being forged in the wild.

1.2 Understanding Live Media Practice

There are many new contexts in which live media is being used to support online communities, including many of the recent live media platforms such as Twitch, Facebook Live, Periscope, Google Hangouts, and YouTube Live. These platforms are also being used in a number of specific contexts, such as online learning, activism, and video game playing.

In order to develop a deep understanding of some of these new live media practices, we conduct qualitative investigations of situated live media contexts. We rely on qualitative data gathering techniques, such as participant observation, interviews, and field notes. To develop understanding of the observed phenomena, data is then analyzed using qualitative analysis techniques such as the constant comparative method and grounded theory [27, 28]. We focus on video game live streaming practice on the Twitch platform as well as the use of live media to support online learning experiences in massive open online courses (MOOCs). We briefly introduce these investigations here. We later present these studies more thoroughly in Chapters 3 and 4.

1.2.1 Streaming On Twitch

Twitch is a live streaming site where people watch and interact with streamers who video broadcast themselves playing video games. In 2011, Twitch was spun out of Justin.tv, a live streaming site, which focused on broader live streaming content, not just video game play. Live streaming on Twitch quickly became a popular social phenomena with millions of unique viewers visiting the site every month to watch other people play games [29]. It was clear that video game live streaming was an exciting emerging online phenomena, and we were interested in investigating how live stream communities formed.

Our research questions focused on understanding the practices and social activies of live streaming communities. What were people's roles and motivations? What role did live streaming media have in how these communities formed and functioned? To investigate these questions we conducted an ethnographic investigation of Twitch involving many years of participant observation and participant interviews.

Through analysis of our observations and interview data, we found that core viewer motivations included wanting to participate and have impact in live experiences and being recognized by other stream community members. We also found that viewers want to learn about and spectate exciting game play. We also examine how live streams as a medium combine live streaming video with text chat. This combinations affords the sharing of rich game play experiences through hot live streaming video and participating peripherally in those experiences through the cool text chat. We

present and discuss these findings more in Chapter 3.

1.2.2 Live MOOCs

Massive open online courses (MOOCs) began to emerge starting around 2012 [30]. MOOCs typically cover university level content and are frequently designed and managed by high-profile universities, such as Massachusetts Institute of Technology and Stanford University. These courses usually offer pre-recorded video lectures free for students to watch, published either through YouTube or one of the MOOC platform websites (e.g. edX, Coursera, or Udacity). MOOCs have drastically increased the reach and scale of online education, often attracting tens of thousands of students. However, we note that MOOCs often rely on impoverished modalities, such as asynchronous discussion forums, for involving students in participatory learning activities, which we know are critical for social learning [13].

However, we discovered a small number of MOOCs using live media, e.g. course text chats, Google Hangouts, and live streams, to support students engaging in learning activities. We call these courses Live MOOCs. There is limited research investigating the use of live media forms to support these new emerging learning contexts [31, 32]. Thus, we conducted a survey of current Live MOOCs by manually searching the various MOOC platforms in search of courses incorporating live media forms to support learning activities. This search yielded several courses, which we then observed by enrolling as students. Finally, in order to better understand the motivations and practices of live media use in MOOCs, we recruited students and instructors from two of these courses and conducted interviews with them.

We found that instructors are incorporating these live media activities into their courses in order to encourage students to participate in learning activities and build their course communities. Instructors used live media to support real-time participatory learning exercises for their students such as pair programming and close reading of poetry. We also found that incorporating live media forms in MOOCs, along with prior asynchronous forms, enable unique cross modality participation opportunities. We present and discuss these findings as well as resulting issues in Chapter 4.

1.3 Designing Live Media Probes

Building on the understanding developed through these qualitative inquiries, we work towards transforming live experience through the design of live media probes. These are prototype systems in which we design and implement new forms of live media.

We employ the technology probe methodology introduced by Hutchinson et al. [33]. Technology probes are functional technologies that are employed in situated real-world contexts. They are intended to not only field test new technologies but to provoke and collect data about new experiences. Technology probes are created to inspire users and designers to think critically about new technologies [33].

We present two live media probes. Through Rivulet, we explore how people participate in multi-stream experiences through an assemblage of cool and hot participatory modalities. We then introduce collaborative live media curation (CLMC), a new form of live media where participants can collect and assemble media, including live streaming audio and video, in order to participate and create shared contexts for collaborative learning activities. We briefly introduce these two investigations below and present them more thoroughly in Chapters 5 and 6.

1.3.1 Participating in Multi-Stream Experiences

During our investigation of live streaming practices on Twitch, we observed the emergence of multi-stream events. For example, the DayZ Survivor GameZ was a multi-stream event, where multiple players streamed their view as they competed in Battle Royale style game play [34]. Similarly, in their analysis of Meerkat and Periscope live streaming practice, Tang et al. at Microsoft Research observed interesting multi-stream experiences occurring around large events like conventions and activist demonstrations [35]. These experiences are interesting because they give participants multiple views into a large event. They also become high profile events, combining multiple social contexts together to form impromptu communities.

However, it was unclear how people experienced multiple streams together and how they could effectively participate in them using existing live media environments. To investigate these issues,

we designed and developed the Rivulet probe, a prototype mobile live-streaming platform. The Rivulet probe supports the simultaneous broadcasting and watching of several mobile broadcasts from an event. To support viewers participating in multi-stream experiences we incorporated a variety of both and cool and hotter participation modalities, including Periscope style hearts, global text chat, and viewer-push-to-talk audio.

We then deployed the Rivulet probe in the situated context of a local music festival. In an effort to create an ecologically valid live streaming experience, we recruited seasoned live streamers from the local area. To create a live-streaming experience at scale, we recruited over a hundred viewers using Amazon's Mechanical Turk.

We found that incorporating these new participation modalities led to new forms of participation. Participants used these new modalities as signals for making decisions about when to focus on a particular live stream. We also found that the Rivulet multi-stream experience resulted in a stronger sense of connection and community among participants than a similar single stream live streaming experience. We present and discuss these findings more thoroughly in Chapter 5.

1.3.2 Collaborative Live Media Curation

In our investigation of Live MOOCs, we examined how live media is being used to support participatory learning experiences in online learning contexts. In this work, we design a new form of live media called *collaborative live media curation* (CLMC) to further explore how new forms might support online learning activities. CLMC builds on Kerne et al.'s free-form web curation (FFWC), which is a computational medium that enables multimedia elements to be spontaneously collected from the web, written about, sketched amidst, manipulated, and visually assembled–in a continuous zoomable space in order to create conceptual and spatial contexts [36]. FFWC has been show to help students engage in visual thinking [36] and creatively engage with prior work to conceive, synthesize, and express new ideas [37].

Collaborative live media curation extends free-form web curation. CLMC integrates live streaming modalities, e.g. webcam video, screenshares, audio, and text chat, to support participating in shared learning experiences. CLMC also enables collaborative and synchronous collection and

assemblage of media, a new participatory live modality.

Part of our motivation for the design of CLMC was to create a media environment that could be freely reassembled collaboratively to enable participants to create an online media place to support their needs. To investigate how this new form supports instructors and students in online courses, we deployed the LiveMâché CLMC probe in four situated online learning contexts. Through this investigation, we discovered that CLMC supports new forms of real-time conversational grounding and participation in online learning activities. We also identify live experience patterns, which are recurring structures of live media experience as defined through assembled media and social roles. We find that CLMC can support a variety of live experience patterns. We further present the design of CLMC and a discussion of these findings in Chapter 6.

1.4 Research Contributions

Through this work, we develop a focused set research contributions concerning the use and design of live media for supporting participatory experiences. The first of which is thick description [38] and analysis of practices and social phenomena in emerging live media contexts. In Chapters 3 and 4 we report on and discuss the live media practices and needs of people engaging in live video game streaming and large online learning communities respectively. We also report on emerging issues in these situated contexts. These findings inform our understanding and are a basis for further research of these and potentially similar situated live media contexts.

We also discuss how live media affords the sharing of and participation in shared experiences. In Chapter 2, we provide a comparative analysis of new live modalities. Using McLuhan's concept hot and cool media, we examine how some modalities afford low and high-impact participation, while some modalities afford sharing high-fidelity views of real-time experiences. We see through our investigation of live media contexts how combining hot and cool modalities supports participation in shared experiences in online communities.

Through our design and evaluation of live media probes, we investigate how new combinations of live modalities lead to new forms, which support new kinds of participation in live experience. In Chapter 5, we see how combining new participation modalities with multiple live streams better

connects participants and creates new opportunities for high-impact participation. With our design and evaluation of CLMC in Chapter 6, we examine how enabling participants to collaboratively collect, assemble, sketch on, and discuss in real-time enables instructors and students to collaboratively create shared contexts for online learning activities. Finally, in Chapter 7 we summarize our findings and consider future research directions.

2. LITERATURE REVIEW: ASPECTS OF LIVE EXPERIENCE, MODALITIES, AND CONTEXTS

In this chapter, we examine prior research literature in the field of live media. We first address approaches employed in recent live media research. Then, through a grounded, constant comparative approach, we identify and discuss prominent aspects of live experience and their related research problems in the field. We then categorize publications based on these aspects. Using the lens of McLuhan's Hot and Cool Media, we then identify and discuss six categories of live modalities, which we derive from their inherent fidelity and potential for individual participatory impact. We then briefly consider the range of situated contexts investigated in live media research. Finally, we discuss implications of the presented analysis.

2.1 Research Approaches

In live media research, we observe two prevailing approaches: 1) investigating existing live media practice, and 2) designing and evaluating live media research prototypes. Tables 2.1 and 2.2 provide an overview of existing practice and research prototype investigations, respectively. We briefly comment on and discuss these approaches here.

2.1.1 Investigating Existing Live Media Practices

Some publications address studying and understanding existing practice across a variety of social contexts and communities that involve streaming video and other live media forms (Table 2.1). Among these, some examine professional use and production of live media. For example, Engström et al. investigated production practices of professional live hockey broadcasters [50]. Other work examines amateur live media contexts, such as Tang et al.'s investigation of emergent live streaming practice on the Meerkat and Periscope live streaming platforms [35]. These investigations inform our understanding of the affordances of these media and the practices of the communities they support. We note that subsequent chapters of this dissertation investigate media practices in the situated contexts (Chapters 3 & 4), following this paradigm.

Table 2.1: An overview of publications investigating already existing situated live media practices. We focus on the modalities and aspects of live experience each addresses, such as participation (P), awareness & presence (AP), and media creation & management (CM).

		Aspects of Live Experience			
Publication	**Description**	**P**	**AP**	**CM**	**Modalities**
Shamma et al. 2009 [39]	An investigation of DJ live streaming practice and audience participation on Yahoo! Live. Explores audience awareness through viewer video streams.	•	•	•	live video, text chat
Juhlin et al. 2010 [40]	An early investigation of mobile live streaming production practices on Qik and Bambuser.			•	mobile live streaming
Juhlin et al. 2014 [41]	An ethnographic investigation of Pro-Am video production and learning practices.			•	live broadcast video
Engström et al. 2008 [42]	Qualitative investigation of professional live video production.	•		•	live broadcast video
Seering et al. 2017 [43]	An investigation of the tools and practices used to influence and promote positive behavior in live streaming communities.	•		•	text chat, moderation tools, live streaming
Dougherty 2011 [44]	Mobile live streaming production as a form of civic engagement.	•		•	mobile live streaming
Webb et al. 2016 [45]	An qualitative investigation of distributed and co-present live performance experience aspects including performers' awareness of audience.		•		live video and audio
Velt et al. 2015 [46]	A study of remote experience of a music festival including immersion and sociable aspects of the experience.		•		broadcast TV, radio, live streaming, VODs
Lessel et al. 2017 [47]	A study of live streaming practices and modalities for audience engagement including Twitch Plays, voting, audience submitted content, and twitter.	•			twitch plays, polls, audience media sharing
Hamilton et al. 2014 [48]	A study of live streaming practice on Twitch and how live streaming modalities afford community formation through participation and shared experiences.	•			live video, text chat
Tang et al. 2016 [35]	A study of live streaming practices and participant motivations on the mobile live streaming platforms Periscope and Meerkat.	•			mobile live streaming, text chat, hearts, likes
Lottridge et al. 2017 [49]	Investigation of teen live streaming practice on third wave platforms including Instagram, Twitch, YouNow, Facebook Live, etc.	•	•		live streaming

2.1.2 Designing and Evaluating Live Media Prototypes

Alternatively, there are many examples of investigations that utilize prototypes designed by researchers to explore live media phenomena (Table 2.2). Many of these investigations use a methodology resembling technology probes, which are functional technologies and prototypes that are deployed in situated real-world contexts [33]. They are intended to field test, provoke, and collect data about new experiences.

To this end, some investigations simply deploy existing modalities and technologies in new contexts. For example, in Coetzee et al.'s investigation of text chat in MOOCs, they deployed and evaluated the use of real-time chatrooms in an online course [31]. Other works create prototypes that implement new media forms or combinations of modalities, which researchers then deploy and evaluate in situated contexts. For example, Wigdor et al. designed and developed WeSpace, a collaborative media assembly environment which they deployed, evaluated, and iterated in a

Table 2.2: An overview of publications that design and evaluate live media prototypes. We focus on the modalities and aspects of live experience each addresses, including participation (P), awareness & presence (AP), and media creation & management (CM).

		Aspects of Live Experience			
Publication	**Description**	**P**	**AP**	**CM**	**Modalities**
Jones et al. 2015 [51]	Understanding emergent camera work practices when using mobile video collaboration to support collaborative tasks.	•		•	mobile live streaming
Yonezawa & Tokuda [52]	Exploring the use of remote controlled cameras and lighting equipment to enable participatory production of live performances including both performers and audiences.	•		•	live streaming, audience controlled lighting and cameras
Engström et al. 2012 [53]	Exploratory study of collaborative mobile live broadcast system exploring the tensions between production and participation in shared experience.	•		•	mobile live streaming
Bentley & Grobel 2009 [54]	Designs and evaluates TuVista, a system for near real-time collaborative production of a multiple mobile live streams at a sporting event.	•	•	•	mobile live streaming
Sà et al. 2012 [55]	Exploratory study of collaborative video production exploring issues around maintaining awareness.	•	•	•	mobile live streaming, awareness cues
Jones et al. 2016 [56]	An exploration of using drones for supporting communication, collaboration, and production of live video shared experiences.	•		•	live drone video
Jo & Hwang 2013 [57]	An exploration of on-video drawing and video control during mobile video calls.	•	•	•	on video drawing, perspective visualization
Wigdor et al. 2009 [58]	Investigates WeSpace, a collaborative media space for assembling live screen shares to support collocated science work.	•		•	collaborative composition space, screen sharing
Rae & Neustaedter 2017 [59], Neustaedter et al. 2016 [60]	Studies investigating using telepresence robots to attend an academic conference.	•	•		telepresence robots
Greenberg & Rounding 2001 [61]	Describes and investigates Notification Collage, which enables the collaborative assembly of media in real-time.	•	•	•	collaborative composition spaces, video, text, and images
Hamilton et al. 2018 [62]	A collaborative live media space for developing shared context and participating in online learning experiences.	•	•	•	collaborative composition spaces, video, audio, text, sketch, text chat, and images
Inkpen et al. 2013 [63]	A study of how to support shared family experiences around kids' activities through multi-stream video chats.		•	•	multi-stream video chat
Procyk et al. 2014 [64]	A study of a shared geocaching experience augmented by mobile live streaming.	•	•		first person live video
Muntea et al. 2015 [65]	A study of shared yoga and meditation experiences supported by live video chat. Specifically supports aspects of connecting and supporting awareness between participants.		•		video chat
Judge et al. 2010 [66]	Study of always on live video portal connections between home to support awareness and sharing everyday life among family members.		•		video portals
Neustaedter & Greenberg 2012 [67], Baishya & Neustaedter 2017 [68]	Study of live video to supporting connecting and providing intimacy between couples.		•		video chat
Dourish & Bly 1992 [69]	A study of a regularly updated images of a workplace for distributed awareness.	•	•		regularly updated images
Roseman & Greenberg 1996 [70]	Describes and explores TeamRooms a groupware for building places for distributed awareness and collaboration through shared media including images, text, and video.	•	•		collaborative composition spaces, video, text, and images
Lessel et al. 2017 [71]	A study of a video game live streaming system to afford new opportunities for audience engagement and communication.	•			audience stream overlays, polls, binary feedback mechanisms
Tang et al. 2017 [72], Singhal & Neustaedter 2017 [73]	Study of 360 degree video use to support collaborative live shared experiences.	•	•		360 degree video
Kim et al. 2014 [74]	A study of mobile videoconferencing augmented with additional contextual information including digital maps, secondary video streams, and high quality still images.	•	•		video chat, multi-streams, still images, digital maps
Hamilton et al. 2016 [75]	A study of how multi-stream experiences and new modalities afford new opportunities for participation and awareness in shared experiences.	•	•		multi-streams, push-to-talk, hearts, text chat
Seering et al. 2017 [76]	A study of audience participation games used to engage audiences in interactive live streaming experiences.	•			audience participation games, text chat, live video

situated context of collocated meetings among scientists [58]. Similarly, in chapters 5 and 6 we present two new live media forms, which we evaluate in the situated contexts of a music festival and online education communities respectively.

2.2 Aspects of Live Experience

We examine here core aspects of live experience and associated problems that live media research investigates. Aspects were identified through an emergent qualitative categorization process based on the constant comparative method [28, 27]. Research publications were read, summarized, compared, and open coded to initially categorize the works based on the research problems and experiences they addressed. Initial open codes included shared experience, production, collaboration, participation, new modalities, connecting, awareness, and moderation. We later engaged in axial and selective coding to form a set of core aspects of live experience, which we present here. Aspects of live experience we discuss include participation, awareness & presence, and media creation & management. We note that these aspects and the research investigating them are not mutually exclusive; there is often significant overlap between the problems and research questions being investigated in each. Tables 2.1 and 2.2 provide an overview of prominent publications in the field and what aspects of live experience and modalities they investigate. In the following sections, we introduce and discuss these aspects of live experience.

2.2.1 Awareness and Presence

Awareness and presence are core aspects of live experience. In their work investigating collaborative writing systems, Dourish and Bellotti define awareness as "an understanding of the activities of others, which provides a context for your own activity" [77]. They argue that there are both passive and explicit forms of awareness, where actors are either unconsciously or consciously deciding to display and perceive signals about their own and others' activities [77]. Schmidt, citing ethnographic investigations of collaborative practice [78], later dispels this dichotomy, by claiming that "displaying and monitoring are thus complementary aspects of the same coordinative practices" [79].

Additionally, Dourish and Bly argue that awareness encompasses understanding social context:

> 'Awareness involves knowing who is "around", what activities are occurring, who is talking with whom; it provides a view of one another in the daily work environments. Awareness may lead to informal interactions, spontaneous connections, and the development of shared cultures - all important aspects of maintaining working relationships which are denied to groups distributed across multiple sites' [69].

This conceptualization of "awareness" coincides with the concept of "social presence", which Biocca and Harms define as:

> 'a sense of being with another in a mediated environment, social presence is the moment-to-moment awareness of co-presence of a mediated body and the sense of accessibility of the other being's psychological, emotional, and intentional states' [80].

Much of the research on awareness and presence focuses on awareness mechanisms, which are modalities and interface features that enable users to passively and actively communicate and perceive activity and social context. For example, Dourish and Bly investigated the use of periodically updated images, i.e., low frame rate video, to support awareness in a distributed workplace [69]. Other work has investigated the use of video chat [67, 68, 73] and "video portals" [66]—fixed, always on video connections—to support awareness and presence for physically separated couples and families. Other work investigates the use of lower fidelity awareness mechanisms, such as telepointers, to support awareness in collaborative workspaces [70]. New modalities, such as telepresence robots, also support awareness and even physical presence for remote participants in shared experiences [59, 60].

2.2.2 Participation

Beyond being aware of others in distributed environments, live media enables people to participate and have impact in shared experiences and collaborative work. McMillal and Chavis argue that participation is critical to the development of emotional connections in communities [18].

Putnam argues that participation in political, civic, religious, and informal associations is a critical part of human society [11]. Further, Lave and Wenger argue that participation in communities of practice is how humans engage in social learning [13]. Thus, supporting participation in online communities and society is an important problem, one that live media is particularly suited to addressing. There are a number of publications investigating how to support participation through the application and design of live media.

One approach is to investigate how particular live modalities afford participation. Every modality affords different ways of communicating ideas and how those ideas are perceived by others, which determines how a person can participate in a shared experience using that modality. Here we provide some examples of research projects that explore how different live modalities support participation in live experiences. Yonezawa and Tokuda [52] found that enabling remote viewers to control the light and camera angles of live music performance broadcasts engaged viewers and helped connect performers and their audiences. Hamilton et al. found that text chat afforded relatively large-scale participation in live streaming [48] (i.e. Chapter 3). Seering et al. later explored how audience participation games can engage viewers of live streaming experiences [76]. Later, we provide a more detailed discussion of how modalities afford participation.

Other work explicitly explores participation in the production of live media. For example, Engström et al. conducted a qualitative investigation of how teams work together to produce live TV broadcasts [42]. Participation in the production of live media can also be considered as itself a form of participation in society. For example, Dougherty, in her early investigation of mobile live streaming, examines how live media production can be a form of civic engagement and participation in activism [44].

2.2.3 Creation and Management

Finally, there is another of body of work focusing on the creation and management of live media. Much of this work focuses on understanding the tools and practices currently being used to create and manage live media in situated real-world contexts. For example, Juhlin et al. [40] and Dougherty [44] reported on early mobile live streaming production practices. Juhlin and Engström

later reported on the practices of amateur [41] and professional [42] television broadcasters. We note that not all of this work investigates the production of live video. For example, Seering et al. investigated the use of text chat moderation tools and behavior modeling practices to encourage pro-social behavior in live streaming [43].

Other work investigates how to support media creation and management through the design and deployment of new tools. Engström et al. explored systems supporting the collaborative production of mobile live streams [50, 81, 53]. Sa et al. designed an application supporting collaborative production of live mobile broadcasts by providing awareness of nearby broadcasters [55].

2.3 Participatory Live Modalities

In this section, we discuss live modalities that are both in common use and that have been investigated in prior research. In particular, we examine these media using the framework of McLuhan's hot and cool media [12]. We then discuss the trade-offs between media fidelity, participation, cognition, scale, and impact. Using these qualities as a lens, we then present and discuss categories of live modalities.

2.3.1 Media Participation, Impact, and Fidelity Trade-offs

McLuhan's concept of hot and cool media suggests a trade-off between media fidelity and participation. The common definition of fidelity is how effectively a media reproduces a real-world phenomena. However, in the context of this discussion, we also consider fidelity to describe how a particular media form is or is not readily perceivable or cognitively demanding. We can think of fidelity as a way to describe how perceptively saturating a particular form is. Beyond fidelity, we posit that human cognition, audience size, number of participants, and impact of participation are also related factors, when considering a particular modality in a situated context. We define *participation impact* as the extent to which an individual participant can influence an experience by taking direct action and communicating with other participants. Here, we work to describe and discuss the relationships between these factors.

First, we consider media fidelity. For a small number of participants, when we switch from

using a lower fidelity medium to one that has higher fidelity, say from text to video chat, we will see an increase in the impact of an individual's participation. The medium is higher fidelity, so an individual's communication demands to be perceived and interpreted, leading to more impactful participation. The key here is that there is a relatively small number of participants, enabling other participants and audience members to readily perceive all interactions.

However, as a larger number of participants become involved, we will see a decline in the impact of an individual's participation. This is due to the difficulty of simultaneously perceiving multiple higher fidelity media streams. We consider two participants engaging in an activity, where each participant is sharing a live video stream of themselves. This is a fairly simple interaction, in which both participants can have significant impact. However, human attention is finite. So as we increase the number of active participants with video streams to ten, it becomes much harder for participants to mutually perceive each other's actions. As we increase the number of simultaneous participants to fifty, it becomes almost impossible to perceive what most participants are doing, at any point in time. Thus, the impact of an individual's participation, using a specific modality, starts to quickly decline at a threshold number of participants.

It is important to note that the point at which this decline starts and the rate at which it occurs depends on the fidelity of the modality. When we consider a low fidelity, i.e. cooler, modality, such as text chat, we see a much larger threshold for when breakdown starts to occur, than say video chat. Group text chats can grow fairly large before it becomes difficult for participants to read every chat message. Jones et al. found that internet relay chat (IRC) rooms can have as many as 40 active participants, before breakdowns occur [82]. However, a large number of active participants in a text chat, beyond this threshold, will strain the ability of each participant to read and respond to messages. In this way, lower fidelity media afford more participation, by supporting a larger number of participants, each with lower individual impact. At the same time, higher fidelity media afford more impactful participation, but for a smaller number of participants.

2.3.2 Media Fidelity and Participation Impact Relationship

In this section, we work to more concretely describe the relationship between media fidelity, number of participants, and participation impact. High fidelity media streams take more attention, i.e. hot media, thus, without overwhelming human attention, fewer participants can actively engage through them. Cooler media streams take less attention, thus more participants can actively engage. Higher fidelity media affords more impactful participation for a smaller number of people.

We also consider the size of the audience, which we define as the number of people actively participating plus those monitoring but not engaging. It is clear that the size of the audience directly affects the impact of an individual's participation. A larger audience implies a larger impact due to an increased number of people who are made aware of an individual's contributions

We use equation 2.1 to quantitatively describe this media fidelity to participation impact relationship for a particular modality.

$$Impact = \frac{N_{Aud} F_{Mod}}{(1 + F_{Mod})^{\max((N_{Part} - T_{Mod}),0)}} \tag{2.1}$$

Here, $Impact$ describes an individual participant's potential for impact in the shared experience. N_{Aud} and N_{Part} are the size of the audience and number of active participants respectively. The size of the audience includes the number of participants, so $N_{Aud} >= N_{Part}$. T_{Mod} is a threshold number of participants for a specific modality, where a human observer can no longer easily perceive every participant.

The fidelity coefficient, F_{Mod}, is a value between 0 and 1 describing the fidelity of the specific modality, with a lower value representing a lower fidelity. For example, we ascribe fidelity coefficient values of 0.05, 0.4, and 0.9 to the modalities of text chat, audio chat, and video chat respectively (Figure 2.1). This describes text chat's relatively low fidelity, and video chat's relatively high fidelity. We can imagine lower and higher fidelity modalities such as sending hearts or virtual reality streams, that would have lower and higher fidelity coefficient values. Audio chat has a moderate fidelity with the moderate F_{Mod} value of 0.4.

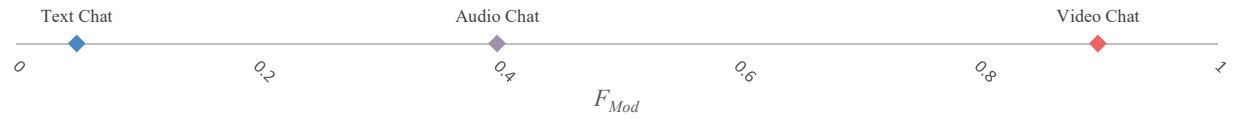

Figure 2.1: An illustration of example fidelity coefficient values. We assume F_{Mod} values of 0.05, 0.4, and 0.9 for text chat, audio chat, and video chat respectively. This reflects the relative low, medium, and high fidelity quality of each modality.

We consider a few examples, which are illustrated in Figure 2.2. Text chat, a low-fidelity modality with F_{Mod} equal to 0.05 and T_{Mod} equal to 40 as per Jones [82]. With a small number of participants, the potential for impact is directly proportional to the size of the audience and the fidelity of the modality. Once the number of participants reaches T_{Mod}, the potential for individual impact slowly starts to diminish (see Figure 2.2). If we consider other higher fidelity modalities, such as audio chat with an F_{Mod} of 0.4 and T_{Mod} of 10, we see that the potential for impact with smaller numbers of participants is higher than that of text chat. However, that potential starts to quickly diminish after T_{Mod} is reached, as individual participation becomes harder to perceive with

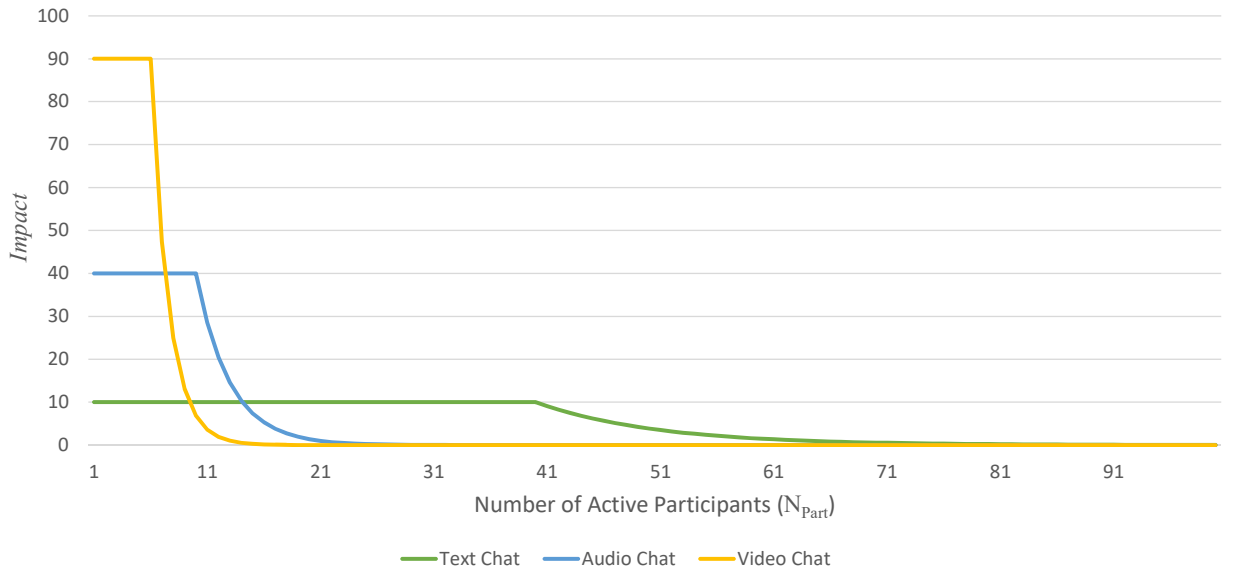

Figure 2.2: An illustration of the relationship between modality, number of participants, and potential for individual impact. This example assumes the size of the audience (N_{Aud}) equals 100. The number of participants (N_{Part}) indicates how many people are participating through the modality.

more participants. If we consider video chat, an even higher fidelity modality with F_{Mod} equal to 0.9 and a T_{Mod} of 6, we see that it offers even more potential for impact at lower numbers of participants, but falls off extremely quickly after the relatively small threshold is reached.

Thus, we can see that higher fidelity modalities afford more impact for participation at lower numbers of participants. However, lower fidelity modalities will provide more opportunity for impact as more participants engage. Though, at a large enough scale, participation impact will eventually break down regardless of modality.

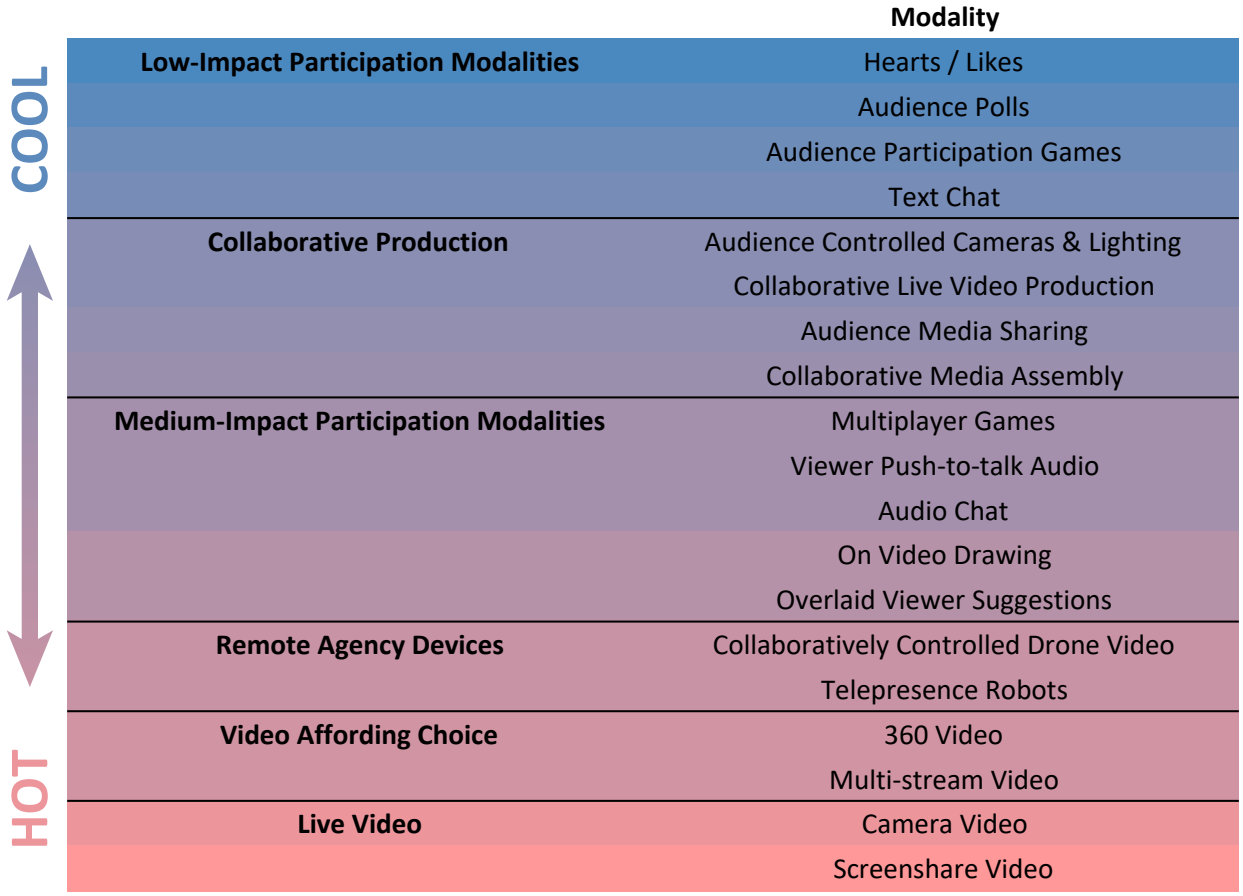

Figure 2.3: A media temperature spectrum, of live modalities, from cool to hot. Media temperature is, by and large, related to how participation is afforded and inversely related to fidelity. Impact can be considered across these factors, involving how much particular individuals affect live media experiences, as well as how many individuals can achieve such impact through a given modality, in a particular live experience configuration.

2.4 Live Modalities: A Media Temperature Spectrum

Using the lens of hot and cold media and the trade-offs between fidelity, participation, and impact, we identify and discuss an ordering and categorization of live modalities found in live media practice and research. Figure 2.3 illustrates this as a spectrum of modalities from cool to hot and provides the additional breakdown of modalities into categories. On the cool end of the spectrum are the lowest fidelity participation modalities. On the hot end are the highest fidelity modalities that afford little participation. In the following, we discuss these categories and modalities in terms of fidelity, participation, and impact.

2.4.1 Low-Impact Participation Modalities

In this category, we examine some of the coolest live modalities including Periscope style hearts and likes, audience polls, audience participation games, and text chat. These modalities are at the core of participatory live streaming experiences. They support large numbers of participants engaging through them. However, they tend to be low fidelity and afford limited impact in participatory shared experiences.

2.4.1.1 Hearts and Likes

Periscope style hearts [35] or Facebook Live likes are one of the coolest modalities we consider. Hearts are an ephemeral modality for expressing approval or interest, or in the case of Facebook Live expressing one of a small set of predetermined reactions. Hearts and likes are usually represented as an icon that briefly floats across the live stream after a viewer sends it. An almost infinite number of people can engage by sending hearts, making the modality very participatory. However, given the low-fidelity nature of the medium the potential for individual impact on the experience is low.

2.4.1.2 Polls

Similarly, audience polls, commonly used in live streaming practice [48, 47], allow for participants to vote to either express their views or influence the shared experience in some way. For

example, sometimes streamers on Twitch will create polls to determine what game they should play. The poll modality provides a limited number of choices, but polls have the potential for individual participation to be more impactful.

2.4.1.3 Audience Participation Games

Audience participation games are another notable example, which enable audience members to engage in simple game mechanics to have some impact on a game they are spectating. ABC's "Who Wants to be a Millionaire" is an early example of a participation game, where the game rules allowed for audience members to help players by participating in a studio poll [83, 76]. In video game live streaming, audience participation games have become increasingly popular. For example, Choice Chamber [84] is a game where audience members can make choices about a player's in game abilities. Quiplash [85] is a game where live stream audiences can vote to decide whether or not a player win or loses. Seering et al. recently designed and studied audience participation games where live stream audiences could participate by allying with or opposing a streaming player by providing power ups, helping the player's opponent, or choosing whether or not to share information with the player [76]. These games provide the opportunity for many audience members to participate in a live experience, but usually with limited to moderate impact.

2.4.1.4 Text Chat

Text chat is the final low-impact participation modality we discuss. While synchronous text chat has recently emerged as a modality commonly used in live streaming, it has existed as a live modality at least since the 1970s [86]. Text chat relies on the use of written language for participation, making for a significantly more expressive modality than other low-impact participation modalities. However, text is still significantly lower fidelity than other modalities such as voice chat. Large numbers of participants can engage in a synchronous text chat. Jones et al. found that internet relay chat (IRC) rooms could have as many as 40 active participants, before breakdowns start to occur [82]. However, the impact of text chat in many cases is limited given its fidelity. In cases where text chat is used by a large number of participants, the impact of individual messages

drops significantly.

2.4.2 Collaborative Production

In this category, we examine a set of modalities and practices involving the collaborative production of live media, media sharing, and collaborative media assembly. These modalities and practices enable participants in some situations to have significant impact through visible contributions. In most situations though, only a moderate number of participants can engage in collaborative production activities.

2.4.2.1 Collaborative Production of Live Media

Collaborative live media production is a recurring topic in the literature. In particular, there are a number of projects that design and evaluate systems to support collaborative creation of live streaming video. For example, Engström et al. designed a system for supporting collaborative production of mobile live video [53]. The system enabled multiple participants to collect live video, which is then combined by another participant using a specialized mobile application. Sá et al. later designed and evaluated a similar system, which incorporated features to help support awareness between collaborating streamers [55]. Other work has investigated more professional production practices of live video broadcasts [42]. The creation, contribution, and mixing of live video is an impactful way for participants to engage in shared experiences. However, we normally see a limited number of participants able to engage in collaborative production.

Other work has explored the use of participatory modalities that give participants limited but slightly more impactful ways to participate in the production of a live experience. For example, Yonezawa and Tokuda designed and evaluated a live streaming prototype that supported audience controlled cameras and lighting during a live music performance [52]. Enabling a live audience to control the production equipment in this way, gives participants a direct, moderately impactful, way of participating in the production of an experience.

2.4.2.2 *Audience Media Sharing*

Another practice that we commonly see in live streaming is audience media sharing, where viewers create and share media that is incorporated into the experience. For example, it is a common practice for viewers to submit drawings or other artistic media they have created to participate in a live stream [48, 47]. This media is often incorporated by streamers as video overlays for everyone to see. In this way, audience submitted media functions as a higher fidelity and higher impact way to participate in the creation of a live experience.

2.4.2.3 *Collaborative Media Assembly*

Collaborative media assembly is a media form that combines the previous practices of collaborative production and audience media sharing. Collaborative media assembly first enables the collection or sharing of media elements by multiple participants in a shared visual space. Participants can then assemble media elements using visual transformations to collaboratively construct the space.

Roseman and Greenberg's TeamRooms work is one of the first instances of collaborative media assembly that we see in the literature [70]. TeamRooms enabled a small team of collaborators to collect media including text, images, applets, and other information sources in a shared digital space, which could then be visually arranged to support collaborative activities. Greenberg and Rounding's later work on the Notification Collage groupware is another instance of collaborative media assembly [61]. Notification Collage enabled participants to collect and share low frame rate views of themselves in a media space. These views could then be selected to start-up higher quality video and audio connections between participants. Wigdor et al.'s WeSpace, a collocated media space for assembling screen sharing video to support scientists' collaboration, is another example of collaborative media assembly [58].

Collaborative media assembly enables participation through collection and assembly of media. Depending on the context, this can be a relatively high-impact form of participation, in which a moderate number of users can engage. In chapter 6, we discuss our work on Collaborative Live

Media Curation, a form of collaborative media assembly which enables the synchronous collection, authoring, assembly, and layering of live video, text, images, and sketch.

2.4.3 Medium-Impact Participation Modalities

In the middle of the media temperature spectrum, we discover modalities that afford audience participation at a moderate level of fidelity. As such, these modalities tend to afford higher impact participation than very cool modalities, but only for a middling number of participants. They offer less impactful participation than the hottest modalities, but more participants can effectively engage through them. Modalities we examine in the category include multiplayer games, voice communication, drawing over video, and overlaid viewer suggestion modalities.

2.4.3.1 Multiplayer Games

Multiplayer games have long served as a modality for engaging in shared experiences with other people. Multi-User Dungeons (MUDs) emerged early on as a participatory game form [87]. Later more complex games, such as Blizzard Entertainment's World of Warcraft [88] and StarCraft [89], emerged as new environments for participating in real-time online experiences. Over the years, playing multiplayer games have become an increasingly higher fidelity form of participation in live experience. Modern games are visually complex and provide complex mechanics for players to engage through. Further, with the emergence of video game live streaming, many multiplayer games shifted towards a more spectating oriented experience [90, 48]. This has served to increase the potential impact of participation in multiplayer games, as larger audiences spectate play.

2.4.3.2 Voice Communications

We next consider voice communication modalities, including audio chat and push-to-talk (PTT) audio. While spoken language is an ancient cultural practice, remote voice communication has only been possible since the invention of the telephone in the 19th century. For our purposes, we consider audio chat to include voice communication media, such as the telephone or digital voice communication media like Skype (without video) or TeamSpeak, where more than one person may freely speak in a shared audio space. In contrast, PTT audio is more constrained. Participants share

a communication space, but may only communicate one at a time. PTT users must also usually signal they are communicating by performing some action. For example, using a two-way radio usually requires pushing a button on the handset.

As previously mentioned, spoken language is higher-fidelity than written language. Spoken language is more readily perceived by humans and implicitly communicates more meaning than the words themselves through prosody, i.e. tone, rhythm, accent, and other nuances [91]. However, it is difficult for multiple people to participate using spoken language over audio chat or PTT audio. If more than one person speaks at a time, it quickly becomes more difficult to understand what each is saying. Thus, multiple participants must usually take turns speaking. This phenomena is more codified in PTT voice systems, where the system enforces a one speaker at a time policy. Because of these constraints, voice communication modalities support fewer active participants than other modalities like text chat, but individual impact is higher. We examine participation through voice communication in our investigations of the Rivulet and LiveMâché probes in Chapters 5 and 6.

2.4.3.3 On-Video Drawing

Finally, we discuss live modalities that support collaborative illustration and annotation on top of live streaming video. Fussel et al. investigated pointing and sketch gestures on live video to support participating in collaborative tasks [92]. Jo and Hwang explored direct sketching on video to support communication during video calls [57]. Lessel et al. recently designed a collaborative annotation modality for supporting viewer participation in video game live streams [71]. The system enables viewers to participate by making visual suggestions, which are overlaid on top of the streamer's game interface to the streamer. These modalities, despite supporting relatively simple annotations and diagramming, enable high-impact participation. By situating annotations and sketches with streaming video, they become the focal point of the experience and are readily seen by other participants. However, it is unclear how many participants can effectively use these types of video annotation modalities concurrently.

2.4.4 Remote Agency Devices

In addition to sensory presentation media and interaction modalities—which use common hardware platforms, such as personal and mobile computers—new hardware serves as a basis for distinct types of live media. For example, remote agency devices provide a basis for another category of live media, which includes technologies such as telepresence robots and drones. These devices commonly use live streaming video and audio to connect users with a remote place in the world. Additionally, telepresence robots and drones can be moved around the world by the person controlling them, serving as a remote physical avatar.

Telepresence robots commonly feature bi-directional live audio and video media streams, enabling users to see and hear as well as be seen and heard through the robot. Recent work has explored the use of telepresence robots in situated contexts of academic research conferences [60, 59]. They found that telepresence robots supported basic remote attendance and supported those with accessibility needs, but there are still issues around navigation, personal identity, and privacy [60] Other work has investigated how telepresence robots can support conference room meetings and moving hallway conversations in the workplace [93].

Other recent work has explored how unmanned aerial vehicles or drones can be used to support communication and collaboration around shared experiences [56]. While current drones do not support providing a video representation of their user, they still provide significant agency. A remote drone participant can actively look around the environment and collaboratively participate in some tasks [56].

Given the physical presence and agency that these devices afford, they serve as a relatively high impact participatory live modality. They give users the ability to move around in the real world, be seen and heard, and sometimes hold conversations with other people. However, usually only one person can participate or engage through a remote agency devices at a time. They provide a fairly high-fidelity view into the world and representation of the user. Given these qualities, we consider remote agency devices to be hotter, but still relatively participatory modalities.

2.4.5 Video Affording Choice

In this category, we consider a subset of live video modalities that afford choice by the viewer. In particular, we examine multi-stream video and 360 degree video. These modalities, forms of live streaming video, afford choice in that a viewer can make a decision about what to view.

In the case of multiple video streams, a viewer can choose which stream or set of streams to view or focus on. In our investigation of multi-stream experiences (Chapter 5), we develop a system that enables viewers to focus on one of many live stream. We find that participants are able to select and participate in streams that addressed their interests and desire for engagement.

Similarly 360 degree video enables viewers to make decisions about what direction to look in. In their work investigating 360 degree video systems for collaborative tasks, Tang et al. found that 360 degree video enabled remote participants to make choices about where they were looking [72]. They could choose to look around in the environment for landmarks to help the local participant, look at the local participant's actions, or simply look around the world freely.

While these video modalities are relatively high fidelity, they provide a limited means for viewers to actively participate and have impact through a choice about how they watch. In some cases, these choices may be observed and interpreted by other participants in the shared experience. For example, in the Rivulet study, streamers could see how many and which viewers were currently watching them (Chapter 5) [75]. Given these high-fidelity nature of these video modalities, we consider these to be hot modalities. However, given their limited participatory nature, the modalities are cooler than others such as live video without choice.

2.4.6 Live Video

The final category we consider is live video (without choice), which we argue is the hottest modality in this spectrum of live modalities. Live video is a core modality of much live media research, and is a quite flexible modality. While there are many forms of video, we consider camera video and screenshare video. For the purpose of this discussion, we also consider live video to optionally include an accompanying audio feed from a microphone or some other contextualized

audio source. Live video enables sharing a high-fidelity visual representation of either a view into the real world or a digital media context.

Camera generated video, whether from a smart phone, webcam, wearable camera, or studio camera, provides a view of the world from the perspective of the camera's location. This view can be augmented through the use of lenses and filters. Live camera video is a high-fidelity modality that lets the viewer see events in the world at a distance. That could be a view of someone sitting at a table, a football game, the view from a car's dash, or outside the international space station. Live camera video is a visceral modality that enables the projection of a view into reality across space.

Similarly, live screenshare video, captured from an digital device, enables us to share high-fidelity views of experiences that occur on our digital devices. Screenshare video is at the core of live media experiences such as video game live streaming on Twitch (Chapter 3). However, we see that screenshare video is also helpful for sharing views into applications that people use to work [58]. Screenshare video can even enable the recursive views into digital media spaces, enabling people to combine and share other media forms such as text, images, or other video sources.

While we consider live video to be very hot given its high fidelity nature, some forms can be more participatory than others. For example, a video chat session is more participatory than a television broadcast. In most contexts though, a limited number of participants can participate effectively through video streams. For example, if we consider a video chat with just 10 participants, it becomes difficult to observe and pay attention to each participant's feed. Tools can help us switch between video streams, but simultaneous streams in any significant number become difficult to perceive all at once. We note that live streaming video, given its high fidelity nature, is one of the most impactful forms of live media.

2.5 Situated Research Contexts

In this section, we briefly discuss some of the primary contexts in which the live media literature we examined are situated. These contexts include home and family life, the workplace, video games, musical performances, and online learning. While these are some of the most common contexts, we note this collection is not exhaustive.

2.5.1 Home and Families

Live media in the home and family life is a common situated context that has been investigated in the literature. In particular, connecting and supporting experiences for distributed families is a recurring research problem. For example, Judge et al. explored how to connect physically distributed families with their always-on live video prototype the Family Window [66]. Other work has investigated how to support intimacy between couples in long-distance relationships using video chat applications [94, 68, 73]. Inkpen et al. explored how to help remote parents spectate and participate in their children's after school activities using a streaming video prototype affording multiple camera angles [63].

Live media research in the home and with families often revolves around problems of supporting presence and awareness between family members. There is also a focus on supporting family members participating in everyday life experiences. Also given that the setting of this research is often in people's homes, there is usually a need to consider privacy issues in the design of prototypes and when conducting studies.

2.5.2 Workplace

The workplace is another common context in which to investigate live media. Much of the live media research situated in workplace contexts focuses on how to support participation in collaborative work. Another common goal is to support awareness of social context and presence in physically distributed teams. Likely due to expensive technology costs, much of the early research on live media system was situated in workplace contexts. For example, Dourish and Bly's Portholes prototype, which focused on supporting awareness in the workplace, was implemented and deployed in the Xerox PARC offices [69]. Later live media prototypes focus on leveraging live modalities to support collaboration in the workplace including Roseman and Greenberg's TeamRooms [70], Greenberg and Rounding's Notification Collage [61], and Wigdor et al.'s WeSpace [58].

2.5.3 Video Games

Video games emerged recently as a context in which people use live media to share experiences. As [90] noted in their investigation of the emergence of StarCraft as an eSports, video games can drive compelling spectator experiences. In Chapter 3, we investigate the emergence of video game live streaming communities on Twitch [48]. Since then, a number of publications have investigate live media practice and prototypes situated in video game play experiences [47, 71, 43, 76, 95]. Other recent work has explored the design of synchronous communication modalities [96] and awareness cues [97] that are integrated in multiplayer games.

By their nature, video games are engaging, potentially collaborative, shared experiences. This makes video game play a compelling situated context for supporting with live media. We argue this is why video game live streaming on sites such as Twitch has flourished in recent years. We may also consider synchronous multiplayer games as their own form of live media.

2.5.4 Musical Performance

Like video games, musical performances are engaging spectator experiences, that can be participatory or collaborative. Also like video games, we see live media being used to create and share participatory experiences around musical performances. Shamma et al's investigated the use of live media to support online spectating of DJ performances on Yahoo Live! [39]. Similarly, Engström et al. explored the use us of mobile live streaming and collaborative production by Video Jockey's in dance clubs [50]. Jordá developed Faust Music On Line in the nineties, which enable the collaborative real-time collaborative creation of digital music through the use of the an internet based composition tool [98]. There have additionally been other live media investigations situated in the context music festivals [46]. In Chapter 5, we evaluate a new live media prototype in the situated context of a local music festival.

2.5.5 Online Learning

Online learning has emerged as situated context for supporting participation through live media. According to Lave and Wenger, "Learners inevitability participate in communities of prac-

titioners... the mastery of knowledge and skill requires newcomers to move toward full participation in the sociocultural practices of a community" [13]. In this way, learning, as a process, takes place through participation in inherently social situated contexts. Much recent online learning research holds that participation and social engagement are at the core of learning processes [99, 100, 101, 102]. Thus, there is a need to investigate how to support participation in learning, and particularly in online learning where participants are physically and culturally distributed.

There have been a number of recent publications investigating the use of live media in online education to foster student participation. For example, Cambre et al. investigated how to support small-group discussions of 4–6 students in MOOCs using Google Hangouts [32, 103]. Other work has explored how to support student participation through the use of text chat in MOOCs [31]. Hrastinski found that live media in online courses, such as video conferences and text chat, fosters more overall dialogue, addressing task planning and social support [104]. In Chapters 4 and 6, we investigate both existing live media practice and a new live media prototype for supporting participation in situated online learning contexts.

2.6 Implications

We derive implications for the design of live media and associated research, resulting from our survey and discussion. First, we explain how understanding affordances of media with regards to how they are perceived and the participation they afford can inform the design of new forms. Second, we discuss how investigating across the various aspects and context of live experience can lead to new understandings.

2.6.1 Leveraging the Perceptive, Participatory, and Impact Affordances of Media

One of the core goals of the analysis in this chapter is, paraphrasing McLuhan [12], to develop an understanding of media. Building on McLuhan's conception of Hot and Cool media, we discuss the fidelity and participatory affordances of various modalities. We observe how very cool modalities like hearts and text chat support a large scale of participation. Conversely, hot modalities provide high fidelity means for sharing in rich experiences. However, hot and cool is not a strict

dichotomy, but rather a spectrum, as we outline in our discussion.

We also discuss how impact, as an aspect of participation, is an intrinsic factor to consider. The coolest of modalities don't necessarily afford significant impact for those who engage through them. Hot modalities, with their overwhelming fidelity, afford significant impact, but only for a small number of users. Modalities that lie in between, that are both hot and cool, afford moderate levels of participation with moderate fidelity. These modalities offer impact, and not only for those in control, but further, for engaged peripheral participants. We find that it is important to investigate and work to incorporate such modalities in new media forms to foster impactful participation in live experience. We work to do so in our design and evaluation of live media probes in Chapters 5 and 6.

By developing this understanding of the relationship between media fidelity, impact, and participation, our aim is to inform the design of new forms so that they incorporate live modalities that support impactful participation at scale in live experience. We argue that these concepts of hot and cool, i.e., media temperature, fidelity, impact, and scale of participation are critical to understanding how to design and assemble new media forms from component modalities. Future designers may learn from this discussion to inform their work.

2.6.2 Investigating Across Aspects and Contexts of Live Experience

We identify three aspects of live experience in this chapter: participation, awareness and presence, and creation and management. Each of these areas pose unique research questions and problems, and there is a broad spectrum of prior work investigating each. However, we think some of the most interesting problems are at the intersection of these aspects. What does it mean for a media to afford participatory creation and management of media? How do we support awareness of others participating in media creation? How do we design for media creators' awareness of peripheral participants.

Investigating and designing for these aspects holistically is necessary for the creation and application of new participatory live media forms. There are a number of works that investigate across these aspects (Tables 2.1 and 2.2). By outlining these aspects we aim to support researchers in

formulating research agendas around these issues.

Finally, there are number of contexts in which live media is actively being deployed and investigated to support participatory experiences. Each of these poses unique considerations and existing practices to consider. Investigating these practices and the issues surrounding the aspects of live experiences across both existing and new contexts helps build a broader understanding of live media.

3. STREAMING ON TWITCH: FOSTERING PARTICIPATORY COMMUNITIES OF PLAY WITHIN LIVE MIXED MEDIA*

In this chapter, we investigate how the popular new medium of live video streaming, i.e., *live streaming*, fosters participation and community in the situated context of the live streaming site Twitch. Live-streaming combines high-fidelity computer graphics and video with low-fidelity text-based communication channels to create a unique social medium. Live streaming previously was at the fringes of social media, with a small population producing and consuming content. Around 2009, live streams of people playing games began growing in popularity. Four years later, the video game live streaming scene has exploded. Twitch.tv, or just Twitch, a website solely supporting video game streaming, has over 15 million daily active viewers and tens of thousands of streamers [29]. We present an ethnographic investigation of the emergence of communities amidst live streaming on Twitch.

Live streaming, in its current form, enables public broadcast of live audio and video streams alongside a shared chat channel (Figure 3.1). In video game live streaming on Twitch, *streamers*, those who broadcast streams, share live video content of their gameplay composited with a video feed of themselves in real life. Viewers of the stream communicate with the streamer and other viewers through chat. Meanwhile, streamers simultaneously engage in game play and communicate via audio and video. Participation in streams is open. All that is required to chat is a free Twitch account.

To investigate the motivations and practices of live streaming participants on Twitch, we conducted an ethnographic investigation of Twitch live stream communities. We found that people engage in live streaming for two reasons: they are drawn to the unique content of a particular stream, and they like being interacted with and participating in that stream's community. Many

*Edited reprint with permission from "Streaming on Twitch: Fostering Participatory Communities of Play within Live Mixed Media" by William A. Hamilton, Oliver Garretson, and Andruid Kerne, 2014. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1315-1324, DOI: https://doi.org/10.1145/2556288.2557048. Copyright 2014 by Hamilton, Garretson, and Kerne. Publication rights licensed to ACM.

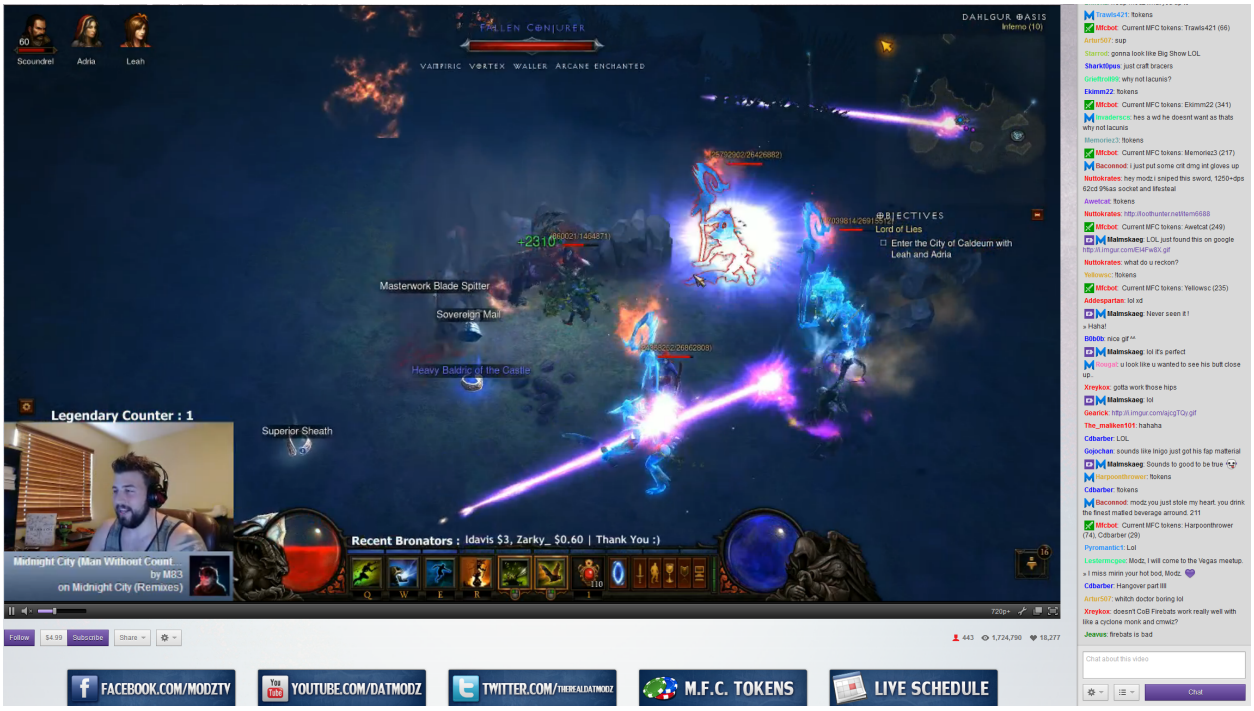

Figure 3.1: A typical Twitch stream. Twitch streams enable streamers to broadcast high-fidelity video of gameplay and real-life. Participants simultaneously communicate through streamed media and an associated chat channel (right). Reprinted from [48].

Twitch streams are what we consider to be *participatory communities*, characterized by openness as well as the means for and encouragement of members to engage in shared activities. The primary activity stream participants engage in is *sociability*, defined by George Simmel as a playful experience of social association characterized by the "sheer pleasure of being together" [105]. Sociability in streams takes the form of humorous banter and light-hearted conversation, alongside play. Core community members engage in key activities: building community by engaging other participants, promoting participation, and moderating chat.

Ray Oldenburg introduces the concept of *third places*, informal public spaces where people engage in sociability to form and maintain communities [106]. We posit that streams function as virtual or online third places. We draw from the concept of third places to discuss the genesis and evolution of stream communities. Stream communities form around a shared identity drawn from the stream's content and the shared experiences of its participants. To analyze stream community identity, we draw from McMillan and Chavis' *sense of community* [18].

We find that dual emphasis on streamed content and accessible participation results from a medium that mixes high-fidelity broadcast with open low-fidelity chat. Beyond fidelity, these various media afford different levels of participation. We use McLuhan's concepts of "hot" (high-fidelity/low-participation) and "cool" (low-fidelity/high-participation) media (Chapter 1) to analyze how components of live streaming contribute to its overall function as a social medium. By combining hot and cool media, streams enable the sharing of rich ephemeral experiences in tandem with open participation through informal social interaction, the ingredients for a third place.

As the popularity of live streaming has increased in recent years, many streams have become very large, some regularly in excess of 5,000 live participants. However, as streams scale up, information overload renders chat unreadable, and moderation becomes overwhelming. Some large streams continue to grow. However, participants become frustrated with the difficulty of interacting in these streams. We found that for this reason, many choose to participate in smaller streams, which they experience as affording more meaningful interaction.

We begin with a socio-technical description of Twitch streams. Next, we present the methodology of our ethnography. We introduce the sensitizing concept of third places[†]. We discuss findings concerning the motivations of stream participants, the formation of stream communities, forms of participation through streaming media, and emergent issues concerning participation. We discuss our findings, and relate prior work. We draw from our findings to derive implications for design. We articulate the role of mixed live cool and hot media in supporting participatory communities. We develop solutions for scaling participatory communities amid large online audiences. We conclude by considering the potential broader impact of live streaming on other contexts.

3.1 What is a Twitch Stream?

Twitch streams combine live audio/video media and text-based chat channels. Streams belong to *streamers*, Twitch users who upload streaming media to be broadcast. Other Twitch users, known as *viewers*, can then watch the streamed content. Video content on Twitch is primarily of streamers playing various digital games, either by themselves or with friends. Streamers often

[†]We also rely on the sensitizing concepts of hot and cool media and sense of community introduced in Chapter 1.

embed in person webcam video of themselves and others they are playing with on top of their streamed game content to facilitate richer engagement (Figure 3.1). Streamed content is not always gameplay, many streamers spend significant time interacting with their viewers out of game.

Every Twitch stream has an associated Internet Relay Chat (IRC) channel. Stream pages have an embedded IRC client adjacent to the streaming video (see Figures 3.1 & 3.2). Within a stream, interaction between participants is typically as follows: the streamer talks through the stream's broadcast audio, and the viewers then send messages to the streamer and each other in the chat. The streamer will typically try to read the chat and respond to viewers as they play.

We describe several types of viewers to convey the topology of a typical stream community. Every stream has *followers*. By following the stream, these viewers choose to receive email notifications when the stream goes live. Some viewers become *moderators* ("mods"), are given the privileges to perform administrative duties within the stream. Moderators are given a special icon in the chat client to denote their status. They have the power to permanently ban or temporarily timeout viewers. Normally moderators exercise these powers to prevent people from posting abusive messages or links to inappropriate websites. Streamers are moderators and can promote stream viewers to be moderators. As we will see, moderators often perform a variety of other tasks to support the stream community.

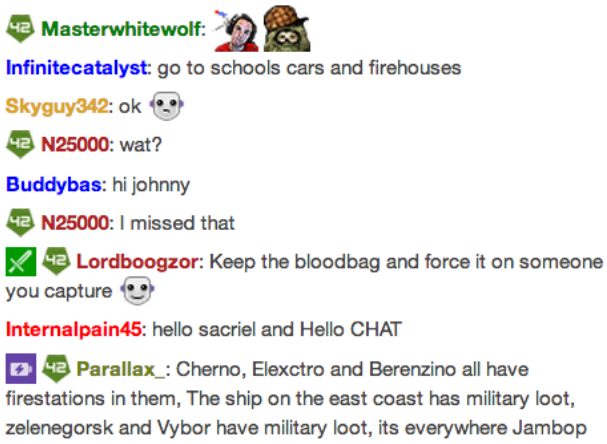

Figure 3.2: An example Twitch stream chat channel. Twitch uses a custom IRC client with special features for showing stream specific emoticons and denoting stream subscribers and moderators. Reprinted from [48].

Twitch invites some streamers who bring in a certain threshold of views to participate in their "partnership" program. Streamers who enter into this agreement are known as *partners*. Twitch partners earn a share of the ad revenue generated from their streams and can choose when and how ads appear on their stream. The revenue that streamers may earn from ad impressions varies between 2 and 5 USD per 1000 impressions. Along with the money from ads, Twitch partners can offer "subscriptions" to their viewers. *Subscribers*, viewers who purchase stream subscriptions, pay a monthly fee to Twitch, half of which goes to the streamer. Subscribers do not have to watch stream ads. They may also use the stream's special emoticons and are denoted by a icon in chat (see Figure 3.2). Streamers often offer additional incentives for subscribers in the form of more opportunities to interact with them on stream. With all of these potential revenue sources, more streamers are going full-time, quitting their jobs, and attempting to live the dream of being payed to play video games.

3.2 Methodology

To construct an understanding of streaming practice and communities, we conducted an ethnographic investigation of live streams on Twitch. This study began informally, in early 2010, when I became aware of the video game live streaming phenomena[‡] around the release of Blizzard Entertainment's StarCraft II: Wings of Liberty [107]. I participated in a number of streams on Justin.tv that focused on StarCraft, with the intent of becoming a better player. Over nearly four years, I became immersed in the Twitch community, as a whole, and a plethora of particular stream communities. I have occasionally live streamed myself, and I still regularly participate in Twitch streams to this day (2018). As a result, I have developed deep firsthand knowledge of the stream viewer experience, streaming practice, and communities. In addition to my long term involvement, we interviewed 11 Twitch streamers and 4 viewers during 2012 and 2013.

Initially, we specifically chose to interview streamers, because of the core role they play in streaming communities. Most streamers spend hours everyday not only streaming, but trying to build a stronger understanding of streaming phenomena and interacting with other stream com-

[‡]It was specifically just the author who was involved at this early point. Thus, the use of the pronoun "I".

Table 3.1: Streamers interviewed, ordered by number of followers. Reprinted from [48].

ID	Followers	Average Viewer Count	Partnered (Y/N)	Gender (M/F)	Frequently Plays
S1	55	15 - 30	N	M	League of Legends, Street Fighter
S2	378	20 - 50	N	M	World of Warcraft, DayZ
S3	648	10 - 200	N	M	Ni no Kuni, Surgeon Simulator, Dead Space
S4	2,673	100 - 400	N	M	League of Legends
S5	4,199	100 - 150	N	M	League of Legends
S6	4,654	200 - 400	N	M	DayZ
S7	8,140	50 - 250	N	M	Oregon Trail, Organ Trail, Punch Out
S8	13,463	400 - 600	Y	M	Don't Starve, Shovel-Knights, Terraria
S9	17,245	150 - 2000	Y	M	DayZ, StarCraft 2, EuroTruck Simulator
S10	24,474	150 - 2000	Y	M	Diablo 3, DayZ, Smite, Neverwinter
S11	45,206	400 - 2000	Y	F	League of Legends, HearthStone

munities. This makes streamers a dense source of inside knowledge and understanding. We later decided to interview 4 viewers who are core members of their respective stream communities: interviewing them helped us better understand individual viewer experiences.

In order to build rapport with the interviewed streamers and viewers, we started to participate in their streams' chats during the weeks prior to recruiting for interviews. By doing this, the researchers became part of each streamer's regular viewership. With some of the streamers interviewed, we already had prior rapport, based on our long term involvement in particular streams. This process also helped familiarize us with each stream's community and enabled us to ask participants focused questions during interviews. Once a level of rapport was reached, we went on to recruit streamers via the private messaging system of Twitch.

In selecting streamers for interviews we used a purposive sampling method: selection was based on characteristics both exhibited by the streamer and the stream's community [27]. Time spent as viewers enabled us to ascertain each stream's atmosphere, chat moderation policy, and community. We sought to interview a gamut of streamers from different game communities, at-

Table 3.2: Viewers interviewed. Reprinted from [48].

ID	Streams Followed	Watches	Gender (M/F)	Moderator (Y/N)
V1	52	S11	F	Y
V2	31	S5	M	N
V3	235	S8, S10	M	Y
V4	71	S8	F	Y

titudes, and stream sizes. Table 3.1 summarizes the streamers that we recruited for interviewing. We will refer to the interviewed streamers by the identifiers given in Table 3.1.

In selecting viewers, we similarly focused on recruiting viewers who were active stream participants. We specifically tried to recruit a number of stream moderators. By recruiting these viewers we were able to interview those who had a strong understanding of their respective communities. Table 3.2 summarizes the viewers we interviewed.

Participants were interviewed via audio/video chat, with the exception of S1 and S10, who we interviewed in person. The interviews, which typically lasted between 1 to 2 hours, were recorded, and later transcribed. We used a semi-structured interview format, focusing on each streamer's experiences, their stream's community, and their goals. Many of the questions focused on evoking important moments and experiences from the streamer's tenure. After completing the interviews, we continued efforts to be active participants in their streams.

We proceeded to conduct a grounded theory analysis by first transcribing the recorded interviews. Transcripts were then unitized, breaking them up into units of meaning. We then used the constant comparative method to code the unitized interview transcripts into emergent themes and categories [28, 27]. All codes emerged through the coding process, and were iteratively derived to describe observed phenomena. Other data collected from researcher field notes and reflexive journals were also used in the coding process. In total, approximately 1,700 data units were coded in the analysis.

3.3 Sensitizing Concept: Third Places

We introduce third places as a sensitizing concept to frame our investigation of live streaming communities and media. Oldenburg establishes the concept of third places as "public places that host the regular, voluntary, informal, and happily anticipated gatherings of individuals beyond the realms of home and work" [106]. Third places serve as alternative locations, for people to come together, form, and maintain communities through informal public social interactions. Oldenburg identifies typical third places, such as cafes, coffee shops, and bars. Later, Rheingold connected a study of virtual communities with Oldenburg's third places [108]. Since then, it has been used to describe the roles of various media in the formation of online communities. These include Bruckman and Resnick's work on MUDs [109] and Ducheneaut et. al's study of massively multiplayer online games [110]. We introduce the some of the characteristics of third places, and use them to show how streams function as such.

Conversation is the main activity inside a third place. Participants experience this talk as good, lively, humorous, and colorful. In this way, the third place fosters sociability. Oldenburg discusses how talk in third places is often playful and is situated around games such as gin rummy or dominoes. Conversation becomes continuously driven by play, as participants talk about the players', "slyness, slowness, quickness, meanness, [and] allusions to long-remembered incidents in club history." Indeed, the primary form of participation that occurs in streams is playful discussion in the chat. Discussion is driven by the events occurring in the game being streamed.

Third places have *regulars*, those who frequent the place to enjoy the company of other regulars and newcomers. These people strongly define the place. As Oldenburg explains, "It is the regulars whose mood and manner provide the infectious and contagious style of interaction and whose acceptance of new faces is crucial." Every regular was once a newcomer There are no strict requirements on who can participate. All that is required is a shared understanding that a newcomer is of a "decent sort", capable of carrying on a civil and playful discussion, and that they will likely be seen again. Thus, to become a regular, "One simply keeps reappearing and tries not to be obnoxious" [106]. As we will show, this process of inducting newcomers and the emergence of

regulars plays a key role in the formation and growth of stream communities.

3.4 Findings and Discussion

In the following sections, we present findings on streaming practices and communities. We discuss these findings in light of the sensitizing concepts to clarify the nature of streams as third places and the senses of community shared by their participants. We start by discussing factors that draw viewers to particular streams and how these factors influence stream community identity. We follow this with a discussion of the importance of viewer participation and influence in streams. We then proceed to a discussion of community regulars, addressing their roles in keeping stream communities inviting and promoting stream participation. Finally, we discuss how the streaming medium affords the formation of shared community history, and how it starts to break down in terms of supporting participation as audiences grow larger.

3.4.1 Identification with Content, Streamer, and Community

When we asked viewers about how they started watching streams, almost invariably they responded that they wanted to learn something about a particular game. Many had similar experiences to V1's:

> I [had] just picked up League, and I wanted to improve. Why don't I just look for a streamer ... I found a bunch. I click on one, and this is pretty much how I joined.

Our own induction into the world of streaming started with wanting to learn to become better StarCraft II players in 2010 [107]. McMillan and Chavis note the importance of learning from other community members. He observes that the chance to benefit from the unique competencies of others is a strong motivating factor in community.

A major theme that emerged through our analysis is that streams develop an atmosphere that reflects the streamer's attitude and values. This projection of the streamer's personality then influences those who stay, because their attitudes and values are shared not only by the streamer, but by the community that emerges. For the viewers we interviewed, a sense of friendliness is an important criterion, because it let them feel comfortable enough to talk and interact with others.

Friendliness came up repeatedly throughout the study as important for a healthy stream community. This sense of friendliness was frequently attributed to a streamer's congenial attitude and behavior. Interviewees identified other streamers who exhibit silliness or open anger on their streams. They noted that these qualities tend to draw a similar crowd. Even in these cases, the streamer still generally exhibits a congenial attitude toward their viewers. From a third places perspective, congeniality helps maintain a sense of openness and acceptance.

Several streamers indicated that they notice the reflection of their personality having a beneficial impact on their stream's community. S6 pointed out that this has a quality control effect on the stream; that if the streamer is calm, collected, and respectful, then the stream will attract viewers who are the same. S11 reported that she felt this effect helps her focus her stream and maintain meaningful interactions with her viewers. Female streamers are sometimes targets of sexist behavior. S11 developed strategies for dealing with this in the live streaming medium: "It really depends on the way you carry yourself ... because the attention isn't on me being a girl, its on the game ... if you go to any stream, what they [the streamer] is focused on is what chat will be focused on."

3.4.2 The Importance of Interaction and Influence

McMillan and Chavis describe how communities serve to fulfill their members' emotional needs [18]. In the case of stream communities, many people watch streams for social interaction with other human beings with whom they identify. In the case of V1, participating in S11's stream is one of her primary means of socializing. She explains:

> I'm studying overseas. I find that there is no one that I can really identify with, and then I go online and there are all of these fucking awesome people, and they all like the same games. So it just comes natural to you.

Similarly, V4 is a stay-at-home mom. Participating in S8's stream gives her a chance to interact with others during the day while she is at home with her kids.

Conversely, many streamers stream because they want to build a community. They want to have a place where they can make friends and hang out. S1, S2, S3, S6, S7, S9, and S11 indicated

that an important part of why they stream is because of the associated community and their chance to interact with members. Many see their regular viewers as friends. Their stream is their primary way to bring those friends together and sociably interact with them.

McMillan and Chavis also note that people are drawn to communities in which they can have influence and impact [18]. We observe this sense of attraction in stream communities. Viewers desire to be recognized and interacted with. While all the viewers we interviewed are all very involved in their respective stream communities, it is clear that for less involved viewers, even minimal personal interaction can be rewarding. This is generally understood by streamers. Many make special efforts to recognize every person at least once in their streams. V3, a long time viewer and moderator in many different streams explained that, "There are a lot of people in here that are self conscious, have other certain problems, and just saying hello and being nice to them, you know interacting with them, can really make their day."

Streamers also make concerted efforts to give participants chances to have influence on the stream in ways beyond that possible in chat. A common practice is for streamers to play games with their viewers to give them some time in the spotlight and a chance to stand out. S9 explained, "I think that is a big draw for a lot of people that come to my stream. They want to get a chance to play with the people that they watch." Streamers also create other participatory activities besides direct play for their viewers. For example, we participated in one of S7's streaming sessions, in which he was playing Family Feud, using answers suggested by his viewers.

Polls are frequently conducted on many streams. The streamer will either do a rough poll based on the chat, or create a poll on a site such as strawpoll.me. Polls are often used to decide what the streamer will do at critical points in a game. Polls are also used to make important community decisions. We participated in a poll to determine who should be made a moderator in S7's stream. V1 was similarly made a moderator in S11's stream.

There are many other ways that viewers can participate in streams. One particularly afforded by the streaming medium is the sharing and adoption of fan art created by a stream's viewers. Streamers can easily overlay these digital images over and around the game graphics and webcam

video on their stream. For example, S9 has collected approximately 90 different viewer created artworks. He displays a slideshow of all of these periodically during game load screens. In another stream that focuses on tabletop role-playing games, the streamers accept viewer art of their encounters and display it on their stream during their play sessions. This practice is particularly interesting because it provides a direct way for viewers to have a lasting impact on the stream and make it their own.

3.4.3 Becoming a Regular

Oldenburg describes how at the core of every third place are *regulars*, those people who most frequently visit the place [106]. McMillan and Chavis describes how the more people interact the more they will develop a shared history and are more likely they are to become close [18]. It is the regulars who have invested the most of themselves into the community and who most strongly define its qualities through their participation. By regularly showing up, participants start to build a level of trust and recognition among other regulars, which is hard to develop any other way.

This process of becoming a regular is strongly at play in stream communities. Those viewers who regularly show up, eventually become recognized community members. V1 described this process as it pertained to her becoming a mod and an important part of S11's stream:

> Sometimes people seem to place more eminence [sic] on you, because you are around a lot of the time, and to them you are a crucial element to the entire element of the channel ... according to [anon], I have been a pretty crucial part in helping the community grow. Cause when somebody sees some of their faces all of the time, I mean their names, it kind of helps to give them that sense of familiarity. And that is why we keep coming back.

When asked, streamers often identified regulars as their friends, those with whom they became closest. They felt like these were people that they identified with and could count on to continue as positive parts of their stream's community. When we asked V3 about S10's stream community, which became much smaller during the 9 months between when we interviewed S10 and V3,

he indicated that the community was now mostly comprised of regulars. He reported that the community is now, "Stronger with the amount of people that are there because of how well we know each other now ... everybody kinda feels like they are part of it. That is why we show up every day." In stream communities, regular participation is the primary path to membership, through the development of familiarity, recognition, and history with other members.

3.4.4 Regulars Encouraging Participation and Sociability

During our interviews, we inquired about moderators, because they clearly play an important role in stream communities. What we learned is that most moderators are given the status largely to demarcate them as regulars. This makes them easy to recognize, because they are given a special badge next to their handle in chat. What also became clear is that the role of moderators is not only to keep the discussion in line, but to engage viewers and promote participation and sociability.

This most often involves greeting viewers, answering questions, and trying to connect personally with newcomers. Greeting individual viewers is an activity that can be seen on most streams of a reasonably small size. As discussed before, being greeted is greatly appreciated by many viewers. It is an important part of some stream communities. Question asking and answering occurs constantly on most streams. For V2, having questions answered, his own and other viewers', by the streamer is his favorite part of participating in S5's stream. V1 also indicated that as a moderator, she felt like it was her responsibility to personally connect with viewers. Streamers indicated that the viewers they noticed frequently taking it upon themselves to fill these roles were those that they felt could be trusted to be moderators. Through these roles of community building and promotion of interaction, viewers become core members.

Viewers expect many of these roles to be performed by the streamer. Indeed, many of the streamers we interviewed are happy to perform them. However, they have to split their focus between the game they are playing and engaging with their viewers, which becomes difficult in some games, particularly with large numbers of viewers. Thus, having moderators and other regulars fill these roles helps a stream operate smoothly, and keeps viewers engaged.

According to Oldenburg, a third place's regulars are those "whose mood and manner provide

the infectious and contagious style of interaction and whose acceptance of new faces is crucial." Regulars are the lifeblood of stream communities. They take it upon themselves to welcome viewers, whether newcomers or old regulars.

3.4.5 Shared History through Hot & Cool Media

Stream communities grow and build a shared sense of history through the streaming medium. Both Oldenburg and McMillan note the importance of shared history in the formation of communities [18, 106]. It is a key part of the emotional connection that community members share.

Significant shared experiences in stream communities happen around ephemeral in-game events. We asked participants about favorite moments in the streams they participate in. Many indicated that these moments occur when something unusual happens in the game being played.

> S5: If there is a very exciting moment and I capture some exciting thing that people go crazy about in chat, that is the most rewarding thing.

We note that there are two parts to this kind of experience. The first is witnessing something surprising, the likes of which may never happen again. Seeing something like this live is a compelling feeling, the same kind of feeling that one might experience at a live concert or sporting event. Video games are an interesting context for live streams, because unique ephemeral events happen relatively frequently, and can be specifically created by a streamer.

However, there is a second part to these experiences, in which the "chat goes crazy." It rapidly fills up with messages like "LOLOLOL" or other humorous phrases and emoticons specific to the game or the stream. For instance, "ヽ(ﾟ∀ﾟ)ﾉ RAISE UR DONGERS ヽ(ﾟ∀ﾟ)ﾉ" is a popular phrase on the streamer Imaqtpie's stream. This feedback lets everyone share in the emotional high of the moment. It reminds everyone that they are part of a unique group of people that saw something special as it happened. Streamers also reported that viewers expected them to have webcams, so that they could share their emotional reactions to these events through facial expressions (Figure 3.3).

The combination of cool with hot media affords the development of shared histories through intense game experiences, resulting in the formation of a stream community's emotional connection.

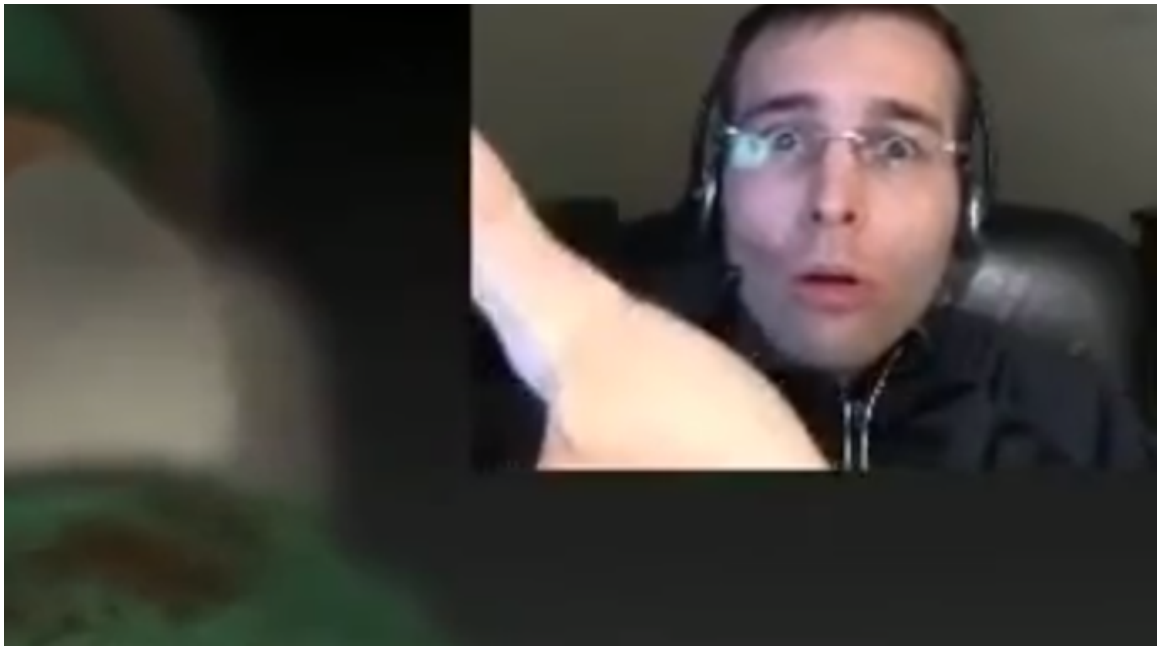

Figure 3.3: An example Twitch stream webcam view. Twitch viewers expect streamers to use webcams, so they can share in their emotional reactions. Reprinted from [48].

Hot live video and game graphics enable audiences to observe unique, rich experiences. Cooler webcam video and coolest text chat enable them to contribute to and experience these things *together*, seeing each other's reactions.

3.4.6 Big Streams and the Breakdown of Participation

We consider streams that draw more than 1,000 viewers to be *massive*. Usually, there are 20 to 60 massive streams live on Twitch. At the time of writing, we sampled a Twitch audience of approximately 440,000 viewers. Roughly, 20% were in streams of less than 1,000 viewers, and 50% were in streams with more than 5,000. The viewers we interviewed watch both massive and smaller streams. In smaller streams, the focus is more on participation, on interacting with other viewers and building community. When watching massive streams, they are there for the unique content available from that streamer. V3 explained this:

> [In] the big streams they are there for the person [the streamer] to be honest. They are not there to talk to a ton of people. They are there for the actual entertainment.

As a stream grows, the chat becomes a source of breakdowns. It transforms from a meaningful medium of discussion into an illegible waterfall of text, scrolling up the page so quickly that it cannot be read. Participants can no longer follow the conversation. At best, they can try to pull out a few comments every so often. When this happens, the one-on-one interaction between stream participants stops.

We note that in streams that are this large, the quality of the chat stream changes to something like the roar of a crowd in a stadium. It is possible to sense an overall feeling of the audience from a few recognized messages and fluctuations in the rate at which they appear. Posting in a chat stream like this is still a form of participation. However, the impact of any one individual is miniscule. Despite not being able to converse meaningfully in these streams, watching these steams is still compelling to some. V2 explained:

> Even if the chat is ... undesirable on the bigger streams, it's still nice to see how sometimes as much as 50k + people go to one place to see one person play.

From a third places perspective, anything that interrupts the flow of conversation is ruinous. Oldenburg cites the use of overly loud music, or the din generated by too many visitors, as ruining the potential of a third place: because it renders healthy conversation impossible [106]. In the same way, overly crowded chat rooms on Twitch streams destroy the potential for communities to form through participation.

When asked how many viewers they could interact with effectively, streamers frequently reported 100-150; some felt they could support up to 500. Past this threshold, they felt personal interaction between them and the viewers breaks down. For various reasons, some streamers want massive streams. Streamers who are full-time rely solely on donations and ad impression revenue for their financial income. This presents a problem, as S10, a full-time streamer reported:

> Honestly, if I could have [only] 150 people in my stream at all times, I would love that. But it's impossible to always have 150 viewers, at least in my position ... because I won't make any money at all.

There are other factors at play. Many streamers seek the fame and notoriety of a large audience. To others, success does not mean having a massive stream. Some focus on building their stream's community for the pleasure of being with those people. S3 and S7 reported that they specifically enjoy their communities, because they interact with their viewers meaningfully. They have been maintaining these communities for years. S3 explained:

> When you get a lot of people in the channel, it will no longer be my channel; it will be a flood of chat. I will no longer be able to keep up and it won't be me, because I won't be able to do what I normally do, and that is give everyone the time to talk. I actually feel guilty when I can't read everyone's chat.

3.4.6.1 Subscribers Only: Sacrificing Openness for Quality

An approach that some large streams have adopted is the use of chat mode called subscriber-only. In this mode, only people who pay a 5 USD monthly subscription fee to the stream can type in chat. The conversation is still public. Everyone can still read the chat, but only subscribers can contribute.

A motivation for subscriber-only mode is to cut down on the inherent noise of having thousands of people together in a single chat room. V3, who is a subscriber to several channels that use this interaction mode, explained:

> If there are a ton of viewers in there, that's why a lot of these sub only chats are a lot nicer. Obviously if you don't have a sub you can't talk, but if you do it's a lot nicer. If you want to be a part of that community and you have enough money to do so then you'll be able to do that and it's no big deal. Obviously, it kind of stinks for other people.

We found this point of view intriguing because it reveals the underlying user need for meaningful interaction. Prior to interviewing V3, our impression of subscriber-only mode was that it was used as a reward for subscribers at the expense of those who cannot afford the subscription.

However, it became clear that, while this may be a factor, some stream communities are searching for ways to preserve their personal interactions despite the ever-growing sizes of stream audiences.

While the use of subscriber-only mode is a kind of kludge to maintain some of the coolness of the chat medium, it fundamentally undermines accessible participation in stream communities. Many streamers who use subscriber-only mode recognize this dilemma and turn it off occasionally or on a specific day of the week. Inevitably, after the mode is turned off, you will see the chat explode with messages like "FREEDOM!" and "RELEASE THE KRAKEN!". Non-subscribers are elated that they can participate in an open chat.

3.5 Related Work

We discuss two areas of online communities research particularly relevant to our own. First, we address the IRC communication modality and issues of information overload in chat based communities. Second, we review relevant work in online game communities. We compare and contrast them with Twitch streams. Finally, we consider eSports phenomena and how they have coevolved with live streaming.

3.5.1 IRC Communities and Information Overload

IRC emerged in the late 1980's as a popular form of computer-mediated communication. It remains widely used today. Reid recognized IRC early on as a compelling communication modality that led to the emergence of intimate real-time online communities [111]. IRC's text chat is essentially a building block of the live streaming medium. Participants similarly engage in stream chats, and suffer similar difficulties. However, without game graphics and webcam video, IRC does not afford the same experiences as a live stream. As discussed above, live audio and video help stream communities develop emotional connection by sharing rich experiences of play.

Jones et al. identify information overload as a major problem of IRC [82]. They apply an information-processing constraints model [112] to investigate how IRC, by removing normal limits on communication, puts increased demand on human information-processing capabilities. As the number of posts increases, participants' capacities to digest and understand dialogue becomes

overloaded. Thus, the number of messages per participant asymptotically approaches 0 as the number of participants increases. The main observable outcome is an inherent limit on the size of IRC channels. Specifically, they find that IRC can support a maximum of 300 concurrent users, with no more than 40 active posters [113].

We see a similar maximum, of 500 participants, in live streams. How are we to interpret then the emergence of streams with as many as 10 to 50 times this many viewers? While it is apparent that these streams often become more spectacle than conversation, we have seen that the shared experiences afforded by hot video are sufficient to loosely bind the stream audience together beyond the breakdown of meaningful conversation.

3.5.2 Participation in Online Game Communities

A large body of work explores social interaction and community formation in multi-player online games [114, 115, 116, 110, 117]. We recognize a connection between communities emerging on Twitch, and those found in online games. In many cases, the lines between these communities blur. For instance, in the early months of S10's stream, he created an approximately 500 member Star Wars: The Old Republic guild, primarily comprised of his stream's viewers.

However, there are subtle differences between contexts. In a live stream, participants do share play experiences. However, most viewers are focused on the streamer's experience. They lack agency in the game world. Consistent with Oldenburg's discussion of a magic circle effect in third places [106], streams afford their own special space somewhere outside that of the game's, and still separate from the rest of the world. The integration of webcam video helps participants connect on a more personal level. Stream participants are not acting through in-game characters. They are acting as themselves.

Another difference is accessibility. Soukup identifies accessibility as a sticking point when it comes to treating computer-mediated communications (CMCs) as third places [118]. He argues while many CMCs are open, many are context specific and require specific knowledge and skills to participate. This issue comes up if we consider in-game environments as third places, as Ducheneaut et al. do [110].

Participation in games often requires considerable skill and engagement. In contrast, a viewer can log onto a stream with little to no understanding of the game being played, making it an accepting place for n00bs as well as veteran gamers. That viewer can then choose the level to which he or she participates, whether passively watching for days, or actively chatting daily for months. A stream viewer can come and go as s/he pleases; whereas, an involved player may be obliged to participate for the duration of a gaming session or raid. This may last 30 minutes to several hours. A gamut of levels is important, because it allows participants to seamlessly interweave their involvement with the third place in-between the more pressing demands of their home and work life [106].

Ducheneaut et al. observe that much interaction in Massive Multiplayer Online Role Playing Games addresses development of reputation and performing in front of others [116]. They predicted that "providing more ways for players to play not only for themselves, but 'in front' of others, would build on this trend." Live streaming instantiates this model of performative play, while supporting the formation of communities.

3.5.3 eSports and Live Streaming

The emergence of eSports, the high-level play and spectating of competitive digital games, has coevolved with the rise of video game live streaming. The phenomena of eSports spectating was explored by Cheung and Huang [90]. They found similarities in spectating traditional and electronic sports. Spectacles of high-level play and information asymmetry in eSports games motivate people to watch. We found that while eSports spectating is a significant live streaming activity, many streams focus not on the highest level of play, but on social engagement and community building.

Kow and Young present a case study of media technologies supporting learning within eSports communities [119]. While they cite the importance of "Internet TV" as a medium, they do not discuss interactive components of live streaming. Kaytoue et al. recently examined Twitch as a platform for live streaming, developing a quantitative analysis of the growth of particular eSports streams [120]. Our research, in contrast, indicates that the formation of participatory communities

is at the core of the live streaming experience. Large streams struggle to maintain meaningful social engagement.

3.6 Implications for Design

We present implications for the design of streaming media systems to support the formation of participatory communities. We show how mixing cool and hot media supports environments that foster the emergence of communities and serve as third places. We consider solutions to the breakdown of participation in large communities due to information overload.

3.6.1 Integrate Cool & Hot Media to Form Third Places

While live streams are comprised of streaming video and IRC, both fairly commonplace technologies, the result is more than the sum of its parts. Cool text chat affords accessible participation and a medium through which to converse, the main activity of the third place. Conversely, hot video affords the sharing of rich experiences, driving the conversation and formation of shared history. The broadcast video of live streams is relatively cool in comparison to other video forms. We have shown how by mixing these media, streams function as third places for emergent online communities. Holistically, the live streaming medium is relatively cool, affording ample room for participation when scale is accounted for.

A key aspect of live streaming's mixed-media integration is that core participants can dynamically control the layout and mixture of visual media in a stream's broadcast. This empowers them to compose the media in situated ways to afford rich engagement through participation and shared experiences. Participants compose the presence, size, and layout of cool media components, such as webcams, chat logs, and viewer art, amidst hot game graphics. This compositing of hot and cool components is essential to the live streaming medium. We prescribe further investigation of how dynamic media composition can support participation in live streaming communities.

3.6.2 Preserve Meaningful Interaction through Subdivision

As we have seen, the scale of streams sometimes grows very large. Large streams initialy draw viewers in with content that is unique and compelling, independent of how many are viewing.

As more people start to watch, a stream stands out more. It draws more new viewers. Further, in many streams there is a sense that the community wants to grow. Streamers, moderators, and regulars interact with newcomers to make the stream inviting. Thus, the stream functions as a third place. However, there are no physical constraints, as in a bar or coffee shop, to keep the number of participants manageable. At a certain point, some streams cross a threshold and go viral.

As we have seen, conversation starts to break down as the audience scales. So what is there to do? We recount a decentralizing practice that we noticed within some Twitch streams. Smaller streamers will sometimes stream as they are watching some other major stream. These other streams, are usually huge and have completely unreadable chats. For instance, S11 recently gathered her comparatively small community of 600 to watch and converse about the League of Legends All-Star event, a stream with more than 200,000 viewers. We find this practice compelling because it enables smaller, already formed intimate communities to participate in large-scale events, while maintaining connection and meaningful interaction.

We hypothesize that, by developing mechanisms to subdivide large followings into smaller groups, we can help maintain meaningful participation. We note that Jones and Rafaeli have previously discussed the potential of splitting virtual publics to maintain legible communication [82]. However, they suggested doing this without regard for prevailing social connections within the group. We argue that, given the importance of shared histories in virtual third places, such as streams, segmentation should not be performed blindly. Randomly grouping people without regard for their interests, existing relationships, and participation history will destroy participants' senses of shared identity.

We propose to account for the vitality of community by building a model representing participants' interests, relationships, and histories. This model will inform algorithms that dynamically subdivide an audience into socially viable subgroups. Given the importance of shared histories, such a system needs to prioritize social continuity, as well as spontaneous encounters. One approach is to keep people in touch with their friends, acquaintances, and core community members, while filtering out other communications. This will enable users to maintain relationships and par-

ticipate, while keeping communication legible. To inform the design of subdivision experiences, we propose drawing conceptual models from physical experiences of small groups in large crowds such as performances, rituals, academic conferences, and political demonstrations.

Given the impact that such subdivision would have on community members' social interactions and relationships, it is important to make such a system intelligible and accountable [121]. Make the model and its impact visible to users. We envision such a tool as mixed-initiative, inferring how to automate the complex subdivision process, while employing dialog to resolve key uncertainties with participants [122]. The system would identify potential social groups and provide mechanisms for dynamically forming them. The system would then clearly present information about identified subgroups to participants, enabling them to make informed decisions about how and when to sub-divide.

Of course, sub-division would not always be needed. It would be used in cases when communication overwhelms a single shared medium. As discussed, having space in which to participate and influence a community is important to members. Sub-dividing so that there is a space for everyone to participate, would be a big step in meeting participants' social needs. We recognize that creating such a system would not be simple. One approach to doing this without denying users' agency is to enable participants to toggle semi-automatic subdivision off and on. Other problems will lie in how to support core members engagement with the whole audience. In any case, user-centered iterative design will be essential.

3.7 Conclusion

Oldenburg discusses the importance of third places in society, due to the social benefits they provide to participants [106]. The assemblage of hot and cool media enable streams to provide an open place for people to go socialize, play, and participate in something larger than themselves. The openness and participatory nature of streaming communities played an important role in our own initial interest. Participating in all of the streams throughout the study was rewarding in that it helped fulfill our own need to find a place to kick back, have a laugh, and be part of a community. During the study, we were always welcome in the different stream communities that

we participated in. We experienced this as inherently gratifying.

We note that when we first started participating in streams, the largest still possessed only hundreds of viewers. Now that so many streams have grown to massive scales, pressure mounts to find ways to maintain streaming communities' participatory nature. We have proposed that this problem be approached through mixed-initiative subdivision into smaller groups that maintain both the sense of community and level of participation sought by stream community members.

The participation and experiences afforded by the cool and hot components of the streaming medium are integral to the nature of stream communities. The emergence of participatory communities on Twitch shows how the integration of cool and hot media can foster third places that broadly impact a gamut of digitally mediated real time experiences of entertainment and education. Cool + hot streaming media methods have the potential to similarly increase the sense of participation in second screen audience interaction experiences, which are being developed for television shows and sports [123]. Likewise, streaming media can help make MOOC education experiences more organic and participatory, and less factory like.

Streaming on Twitch establishes a new paradigm for online communities in a range of emerging contexts. The growing availability of streaming media capabilities will enable broadening impact. At the same time, Twitch has shown us how participation can break down as streams scale. Modeling social user experiences, and using these models to drive mixed-initiative interfaces has the potential to overcome breakdowns and scale participatory communities.

4. LIVE MEDIA FOR PARTICIPATORY LEARNING IN MOOCS

4.1 Introduction

In recent years, massive open online courses (MOOCs) have become popular venues for online education [30]. MOOCs, as their name suggests, are typically offered for free and often seek to scale education, i.e. with tens of thousands of enrolled students. Until recently, most MOOCs have relied on asynchronous media forms, such as prerecorded YouTube lectures [124] and student discussion forums [125]. Alas, these modalities provide limited support for participatory learning experiences in situated social contexts, which have been found to be critical for learning [13, 102]. As a result, MOOC enrollment has dropped [126]. While many students successfully complete these courses, most drop out. Motivating students to sustain participation in massive online courses thus remains a problem [127].

In this work, we investigate some of the MOOC communities that are beginning to use live media forms to engage students in collaborative learning activities with instructors and their peers. We call these situated online course contexts *Live MOOCs*. Initial research has begun exploring the use of live media to support participatory learning activities in MOOCs. For example, Cambre et al.'s Talkabout system enabled small-group discussions with 4–6 students in MOOCs using Google Hangouts [32, 128]. They found that live discussion sessions led to improved class participation and learning outcomes. Other work has found that incorporating text chat in MOOCs made little impact on learning outcomes or course community [31].

However, there is still much unknown about live media practice in MOOCs. In this research, we conduct a qualitative investigation of two disparate Live MOOC contexts, including one course on web service development and another on modern poetry. Both courses incorporate and leverage live media to support novel learning experiences for their students. Through this investigation, we work to investigate the following research questions:

1. What are instructors' motivations for incorporating live learning activities in MOOCs?

2. How do live media experiences impact students and MOOC communities as a whole?

3. What media practices emerge to support learning activities in Live MOOCs?

4. What problems emerge around the use of live media in MOOCs?

We find that instructors are motivated to incorporate live media in MOOCs in order to engage students in participatory learning activities and build course community. We discuss how incorporating both asynchronous and live modalities enables courses to adopt new learning activity structures. Finally, we discuss some open problems we identified in Live MOOCs, including organizing small learner groups, scaling course participation, and differentiating live experiences for paying students.

In the following sections, we discuss our qualitative study methodology and provide a description of both Live MOOCs that we investigated. We then present and discuss our findings. Finally, we conclude by summarizing and discussing future work.

4.2 Methodology

In order to examine and build further understanding of current live media practices in MOOCs, we conducted a qualitative investigation of online courses using live media to support their learning activities. To identify courses of interest, we initially surveyed available courses on the MOOC platforms edX and Coursera. Searching through courses on each platform, we compiled a list of courses using any form of synchronous communication media, including live video, audio, and text. After identifying such courses, a researcher enrolled as a participant student and observed course interactions. We also contacted course instructors to request interviews with them, as well as permission to solicit interviews with their students. After contacting instructors, we decided to focus on two courses that we were able to observe and interview participants in: a web development course using Ruby on Rails and a poetry course focusing on modern American works.

After observing each course's live activities, we recruited course instructors, staff, and students to participate in semi-structured interviews. Interview questions were derived from our research

Table 4.1: An overview of the 10 study participants interviewed including the course they participated in, their gender, and role in the course.

Participant ID	Course	Gender	Course Role
PI	Poetry	Male	Instructor
PC	Poetry	Female	Course Coordinator
PT1	Poetry	Male	Webcast Technical Crew
PT2	Poetry	Male	Webcast Technical Crew
WDI	Web Development	Male	Instructor
WD1	Web Development	Male	Student
WD2	Web Development	Female	Student
WD3	Web Development	Male	Student
WD4	Web Development	Male	Student
WD5	Web Development	Female	Student

questions and focused on participants' experiences using live media in the course and their relationships with other course participants. In the case of course instructors and staff, we asked about their pedagogical motivations for using live media experiences in the course, practices they had developed, and perceived benefits and outcomes.

We interviewed 2 instructors, 3 course staff members, and 5 students. Table 4.1 provides an overview of participants. Interviews were conducted remotely using Google Hangouts or a similar video chat application of the participant's choosing. Interviews were recorded and lasted from approximately 25 minutes to an hour. After completing the interview, participants were compensated with a 15 USD Amazon gift card for their time. The interviews were later transcribed by a researcher.

We then conducted a qualitative analysis of the interview data using the constant comparative method [27, 28]. We unitized transcripts to form units of meaning relative to our research questions. Units were then iteratively coded using open coding to identify emergent themes in the data. High level themes we identified included live activities, live participation, communication modalities, course design, and organizing. We report on some of these themes as findings.

The following sections provide a detailed description of the two course contexts we inves-

tigated. We describe the live media practices, participant roles, and the overall design of each course.

4.3 Course 1: Web Service Development

We first examined the web software course, a MOOC offered on the edX platform. The course centers around instructing and engaging students in Agile Development practice, with a focus on online web service development using Ruby on Rails. The core course content is comprised of a collection of pre-recorded video lectures. However, the students are encouraged to also participate in the course's edX forum, as well as in several live media activities, which we describe in the following sections. We conducted interviews with five students, which we identify as WD1–WD5. We also interviewed one of the course's instructors, WDI.

4.3.1 Live Activity: Pair Programming

In the course, students are encouraged to participate in the live pair programming exercises. Pair programming is a practice in which two programmers work together on the same piece of code or problem [129]. The two participants work asymmetrically. The first participant, known as the *driver*, works to actively type in code. The second participant, known as the *navigator*, observes the work of the driver, looking for any defects as they occur. The navigator also works to actively think about the long-term strategy of the problem and discusses the work with the driver. The driver and navigator periodically switch roles. For the course, the students are encouraged to participate in hour long pair programming exercises, swapping roles halfway through. In industry and in the classroom, pair programming has been shown to lead to higher quality code [130, 131], as well as increased student performance and engagement [132].

In practice, the students engage in pair programming by using a live video chat application like Google Hangouts. The student pair communicates using voice chat through the hangout's live video connection. Instructors encouraged students to organize pair programming sessions using an external website they created, which enabled students to advertise their availability for sessions. During pair programming sessions, students would typically work collaboratively on the

homework assignments or projects. In order to share a view of the code they were collaborating on, students would usually rely on screensharing a code editing application. Alternatively, some students reported using web applications specializing in synchronous collaborative code editing, such as Cloud9 [133]. Instructors requested that students record their pair programming sessions and upload them to YouTube. This was done so that the students could be evaluated on their participation and adherence to the pair programming methodology.

4.3.2 Live Activity: Live Q&As

The web development course also features live question and answer sessions that occur every two weeks. Typically, these sessions consist of the course instructors leading a discussion on a live streamed Google Hangout session. Students have the opportunity to ask questions in the hangout's text chat, which the instructors then work to answer. Occasionally, the instructors invite outside speakers, typically from industry, to participate in the Q&A sessions. This gives the students the opportunity to not only ask the instructors about the course content, but to also interact with people engaged in the wider software development community.

4.3.3 Chat Interactions: Slack & Gitter

The course also relies on two chat channels, Slack and Gitter. Typically, students reported using the chat channels to ask questions about the homework assignments, how to use the course's autograder, or other course administration issues. We also found that students would occasionally use the chat channels to find partners for participating in pair programming exercises.

4.4 Course 2: Modern American Poetry

Next we examined a poetry course studying contemporary American works. When we investigated this course in the fall of 2016, the course had 13,000 enrolled students. The course was originally taught face-to-face beginning in 1986. Its instructor later offered an online version beginning in 2012. The course focuses on reading and analyzing contemporary poetry. The online course is open year long, but operates more actively during an annual 10 week symposium in the fall. During each of these 10 weeks, students are assigned a collection of poems to read. Stu-

dents then respond to these poems with a written essay. Students also discuss these poems using the course's discussion forum provided by the Coursera platform. The forum is divided into sub-forums for each poem, in which students can create discussion threads or respond to other students' threads. Finally, the course offers a weekly live webcast, during which the students, instructor, and TAs discuss the previous week's poems. We describe the webcast in more detail in the following section.

To investigate the course's design and practices, we first interviewed the course's main instructor, identified here as PI. We then later interviewed the course coordinator, PC. She is responsible for a variety of managerial responsibilities, such as preparing for the live webcasts by communicating with remote teaching assistants and distributing PDFs of the week's poems. Finally, we interviewed two technical crew members together, PT1 and PT2, who are responsible for the technical production of the live webcasts.

4.4.1 Live Activity: Webcasts

During the 10 week symposium, the teaching staff gathers once a week for a live 90 minute webcast at a location dedicated to hosting various writing and reading programs at the university. The room has space for a small audience seated in rows of chairs facing a small table at the head of the room. The webcasts are broadcast online on YouTube, as well as Facebook Live. The webcasts are typically attended by between 70 and 200 students, with as many as 300 having attended in one case. During the webcasts, the instructors and TAs lead a discussion about the prior week's poems. These webcasts also provide students with the opportunity to share thoughts and/or opinions on the set of poems assigned for the week. The instructor also draws from ideas shared by students in the discussion forums to seed discussion during the webcast.

During the webcast, the instructor and as many as six teaching assistants sit together at the lead table around a shared microphone (Figure 4.1). For the majority of the webcast, a camera focuses on this table. Some teaching assistants, who are remotely located, join via Google Hangouts. These usually appear overlaid on top of the main table view.

Students are encouraged to participate in the webcast discussion using one of five modalities,

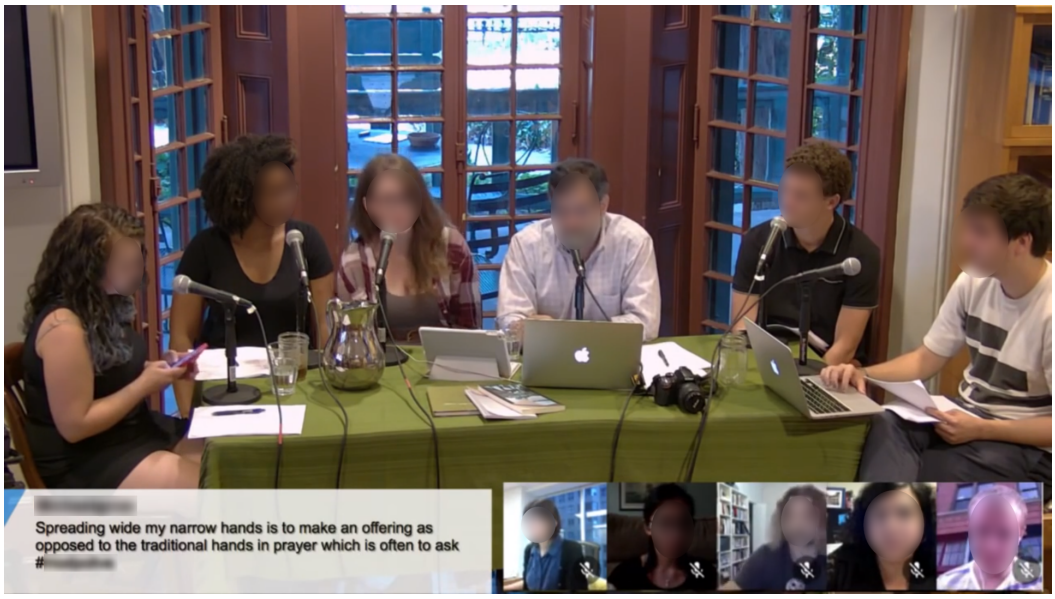

Figure 4.1: A typical poetry webcast view, with the instructor and TAs around a table leading the webcast discussion. They monitor the various student participation modalities using laptops. Remote TAs participate using Google Hangouts. Tweets from participating students are overlaid on the webcast. A phone number is made available for students to call to participate in the discussion.

including calling in by phone, leaving a voicemail, commenting on the live stream on Facebook, tweeting using the course hashtag, or posting on a Coursera discussion forum created specifically for the webcast. A different teaching assistant reads, responds to, and manages each of these communication modalities. The instructor then acts as the moderator, responding to every modality to ensure equal attention. When a student phone calls in, the course coordinator answers the phone off-camera, asking the student for his/her name and what he/she wants to say, waiting until the instructor signals to put the caller on the webcast. At this point, the caller's audio is played over the webcast's audio stream.

Additionally, one teaching assistant scrolls through the Facebook Live comments and highlights interesting points, while another teaching assistant reads through the Coursera discussion forum. Tweets are overlaid on the stream and cycled through, curated by a member of the technical crew. Using the voicemail option, students can call in and leave messages discussing their thoughts. However, this option is less popular. If a student does leave a voicemail, the message is played over the stream, and the instructing staff responds. The two technical crew members, who

sit at the back of webcast room, manage the production of the webcast's video and audio stream. They coordinate with the instructor and with the course coordinator, who answers the phone.

Occasionally, webcasts occur away from their typical location in the event the instructor has to travel. Prior webcasts have taken place in San Francisco, New York, and Washington D.C. During these remote cases, the instructor travels with the technical staff, a few teaching assistants, and minimal equipment, but the webcast structure remains similar. Both local and remote filmings of the webcasts feature live audiences, ranging from a size of two to fifty people, with larger audiences attending remote webcasts. Although audience members are usually off camera, they are sometimes filmed when asking questions and participating in the discussion using an audience microphone.

4.4.2 Other Poetry Activities

Along with the online course, there are several parallel syllabi for students who seek further readings and discussion. The external syllabi contains poems not included in the regular syllabus, targeting students who may have taken the course previously and wish to read different poems. Additionally, the course offers the Community Collaborative Close Readings (CCCR) program, which encourages student groups to meet and conduct independent close readings of poems. Student groups are encouraged to record their meetings and afterwards submit the recordings, which the staff subsequently curates, uploading some to the course YouTube channel.

4.5 Findings and Discussion

We present and discuss findings from our qualitative investigation of the web development and poetry MOOCs. Findings are derived from the emergent themes of our constant comparative coding analysis. We integrate findings into discussion to connect data with our own abstract thinking. We also discuss implications for the incorporation of live media in online courses and future directions throughout. We first discuss how instructors in both courses incorporated live learning experiences in order to promote student participation. We then discuss the role that live media activities play in developing course community. Next we discuss how incorporating multiple modalities,

both live and asynchronous, enabled new ways to structure participation in MOOCs. Finally, we discuss issues we observed in both courses and discuss potential solutions and directions for future work.

4.5.1 Live Media for Student Participation

Some of the core emergent themes that we identified focused on how each of these courses was designed to promote student engagement and participation. Indeed, instructors from both courses identified encouraging student participation, especially through live learning activities, as a goal for their respective courses. As PT2 explained when asked about the course's webcasts:

> The whole point is to encourage participation and create access to us. So it's not just like talking heads on a computer screen. We're like real, live humans who are there and are super interested and want to answer your questions.

Designing for participatory learning in these courses included creating activities where students and instructors do learning activities together using live media. Instructors and TAs also worked to encourage, moderate, and evaluate student participation. In the following sections, we report on the activities and techniques instructors used to promote participation.

4.5.1.1 Doing Learning Activities Together

In both courses, we observed that live experiences focused on core collaborative learning activities. In the case of the poetry course, this core activity was the collaborative close reading, analysis, and discussion of assigned poems. In the web development course, students worked together in pair programming sessions to do their homework and projects. As WD1 explained,

> I never went to pair programming sessions to get help. My goal in the pair programming session was to do the homework, or solve specific doubts of the project.

Doing this work together enabled students and instructors to connect around the shared experience of doing the work, despite being geographically distributed. As PT1 noted, the course staff found this particularly important for learning poetry.

> I think it is particularly [important] for our content, because poetry can be isolating, or maybe eliminating in some way. Especially in terms of our course content, it's good to have a group where you know that you're going through the same things that other people are going through. It'd be a lot harder if you were trying to do this alone.

WD5 commented on the social benefits of the live pair programming experience. He describes how these experiences help students connect emotionally and support each other:

> What happens often in pair programming sessions is that you have to have a lot of compassion. If someone out there is struggling with something, you have to be very compassionate and friendly and help them all, because we are all in the same boat.

Prior work has found that synchronous communication modalities used in online learning have led to increased social support [104]. In the two courses, we see that participating in live learning activities not only provides the opportunity to complete work together, but also fosters emotional connection and support among participants.

4.5.1.2 Encouraging, Moderating, and Evaluating Participation

Instructors explained that the primary reason for offering live experiences was to provide the opportunity for students to participate in learning activities. As PT2 noted, "the whole point is to encourage participation". Beyond just offering the opportunity, instructors and staff in both courses worked to encourage participation. To illustrate how she encourages students to participate in live webcasts, PC narrated an example of how she might engage with a student calling in to the weekly webcast with a question.

> Sometimes people are nervous like, 'Is that a good questions? Should I even ask that? I don't know.' So it could be a nice way to sort of engage like 'No that's a great question, I'm so glad you asked. It's so important to talk about whatever.'

Alternatively, in the context of the web development course, instructors strongly encouraged students to participate in pair programming exercises. They go as far as to make participation

mandatory for students who are taking the course for the certificate. Thus, participation in the practice of live pair programming becomes part of the curriculum of the course.

To verify that students are participating in live pair programming exercises, the web development instructors require that students upload recordings of their pair programming sessions to YouTube. The students must then submit the link to the video for evaluation. The instructors evaluate the recordings based on the students' adherence to proper pair programming methodology and how much the students interact. In particular, instructors verify that participants did indeed switch roles during the session and performed the prescribed work in each role. In this way, the web development instructors worked to promote balanced participation in the pair programming sessions.

During the poetry course's webcasts, the instructor, teaching assistants, and staff work collaboratively to moderate student participation in the limited 90 minute session. The teaching assistants actively monitor and respond to student participation in each of the webcast's communication modalities. PT2 explained that PI wants the live webcast to "mimic his in-class teaching style, which is read a poem then [...] he will moderate a discussion around that poem and will incorporate everyone in the room into dissecting what different parts of the poem mean in breaking it down."

However, there are some modality specific factors to consider when moderating. For example, PT2 explained that PI "usually puts a high preference on phone callers so that we clear up the line." Additionally, when asked about how they moderate other modalities, PT1, who manages the webcast's video feed, discussed how he curates the tweets shown on the live stream:

> I try to avoid retweets. I just want to have the original sender. I try not to put more than two tweets by the same person on the screen at a time, or let one person dominate.

As can be seen by these course practices, instructors work extensively to encourage their students to participate in collaborative learning activities. However, they also work to actively evaluate and moderate student participation to ensure effective and balanced engagement. Future work may

contribute by investigating and designing tools to support the motivation, evaluation, and moderation of student participation live learning activities.

4.5.2 Developing Community through Live Experiences

As previously noted, doing the work of learning together led to an increased sense of "being in the same boat" as described by WD5. We argue that the incorporation of live media in MOOCs fosters this sense of community by help helping students identify with other participants, develop shared history, and derive mutual benefit through participation in the courses' live learning experiences. These are important factors in the development of communities [18].

Indeed, instructors from both courses cited the importance of the live experiences for developing course community. When asked about the importance of the live Q&A sessions in the web development course, WDI explained: "I think that [it] is at least as much about espirit de corps as it is about learning the material." When asked about the importance of the live webcast in the poetry course, PT2 explained that

> It's the same reason people tune into live radio. Why people tweet during TV shows. It's that community aspect and that personal feel.

It is clear that instructors find that incorporating live experiences is critical to the development of course community. In the following, we discuss how we observed live media supporting the formation of course communities through extended participant engagement, incorporation of real-world places and live audiences, and legitimate peripheral participation.

4.5.2.1 Building Community through Extended Engagement

A critical way that live media supported the formation of course community was through supporting extended participant engagement. We observed that live course activities provided the opportunity for students and TAs to continue to participate in the course long past their first semester. In particular, this has helped the development of the poetry course's community. Recalling the history of the course, PT2 explained:

> These teaching assistants were here when [PI] was originally creating the rubric in 2012, but have since dispersed elsewhere in the world doing other things. Some are teaching, some are working elsewhere. So everybody is kind of scattered now. So the virtual participant thing is a way of bringing those people back for live discussions. [The course] is unique in that it's not a single professor but a cast of characters.

Additionally, PC explained that this group of TAs helps form the identity of the course community:

> We've been able to keep for the most part all of the original TAs that we had in the beginning discussions videos. And that's given this class this continuity I think that's really powerful and why people come back year after year. You don't get too many people who just do this once. I would say a lot of people tend to come back.

As PC explains, the continuity of the community and the sense of identity that it elicits doesn't just motivate the TAs. The extended engagement of the TAs also helps motivate students to return to the course and participate in subsequent years. PT1 explained that the live webcasts are also a way in which engaged students regularly participate:

> We'll see a lot of the same people come back to dial in a call live. A lot of the same folks on Twitter retweet. Hard core students who won't miss a webcast.

Additionally, the Community Collaborative Close Reading groups are another way in which the students extend their participation in the course's community. The CCCR program encourages students to form small groups to conduct close readings of poems on their own. The poetry course's instructors encourage CCCR groups to record and upload their meetups to YouTube for other students to view. While normally these meetups occur in a physical place, recent meetups have started to take place over Google Hangouts.

In this way, live media is providing a means for MOOC participants to stay involved. Despite being geographically separated or having already finished the course, students and TAs return to participate live every week of the course and beyond.

4.5.2.2 Integrating Physical Places and Live Audiences

During our investigation, we found that the place the poetry course's webcast was situated in was a crucial part of the social context in which the course takes place. Typically, the main video stream of the webcast is a camera view from a large room situated within building on a university campus. This building hosts a varied community of students, faculty, staff, and alumni from the university and the surrounding area. By broadcasting the webcast from this particular location, the poetry course becomes situated in the wider social context of the university's writing community.

One way that the course accomplishes this is by incorporating a live in-person audience during webcasts. The audience typically includes other faculty members, students, and poets. During the webcast, members of the live audience have the opportunity to participate in the discussion using a wireless microphone that is passed around the room. When we asked about the importance of the live audience, PT1 and PT2 explained that:

> PT1: It sort of brings the whole production to life. You wouldn't know that it was a live event if you didn't have that audience there, and it also gives the mobile viewer [a] vicarious perspective to see the webcast. ... PT2: Yeah, it definitely enhances that live community feel being able to see that there are other people out [there] right now somewhere in the world [...] I think it's a really cool thing for viewers.

Beyond helping viewers vicariously connect with the community, the webcast's location also serves as a physical place that online students can visit. PC explained that current and former students frequently visit the building. During our interview she recalled:

> Just today a man came down from Ottawa to visit ... who has been involved with [the course] for several years. He visited, we said hello, took some pictures together, and then he went into a program that ... was [offered] at noon.

In addition to the normal webcast location, the poetry course's team occasionally broadcasts their webcast while travelling. During these webcasts, the technical crew takes minimal production equipment and conducts the broadcast from a remote venue. At the time of the study, the crew

had conducted webcasts in New York, Washington D.C., and San Francisco. Producing the show in other locations enables students in those locations to show up and participate in person in the webcasts. PT1 explained that groups of students in these places would often attend these webcasts, enabling the course to prominently feature and engage geographically dispersed community members.

4.5.2.3 Live MOOCs Support Legitimate Peripheral Participation

Lave and Wenger describe legitimate peripheral participation (LPP) as the social process in which learners transition from new hands to practitioners in communities of practice [13]. They argue that students learn and join the community of practice by engaging in legitimate forms of practice at the periphery. Over time, learners engage in increasingly core activities of the community. We observed LPP phenomena in the web development and poetry courses, in which the students' engagement in live course activities enabled them to engage with the wider community of practice.

For example, in the web development course, students were encouraged to organize through an external website created by one of the course instructors, which lists the availability of other students for live pair programming sessions. WDI explained that "the basic model is programmers pay for mentoring, and to some extent, companies may pay to find candidate who can work on their stuff, or to help them maintain, or make improvements to their apps." In this way, by participating through the external platform, students may transition from learners to budding professional developers. Further, many of the course's community TAs are former students who were recruited after being particularly active on the external platform.

Additionally, in both courses, instructors work to connect students with community practitioners through live experiences. For example, in the poetry course, poets, whose works are featured, regularly participate in the course's live webcasts and the discussion forum. PC explained that:

> The final thing that I think makes this class tick is the way that we actually are able to get poets, whose work we discuss, to come hang out with us in the discussion forums.

> Which is amazing because it's not just that the people who are teaching are living breathing human beings who want to talk to you. It's also that the work you're reading is written by living breathing humans who are interested in what you have to say about their work, and it's really cool.

WDI also reported that they were working to bring figures from the software development industry to participate in the course's live Q&A sessions. By bringing in "celebrities" to engage in the courses, through both synchronous and asynchronous activities, instructors provide students the opportunity to socialize and participate legitimately in the wider communities of practice.

4.5.3 Participating Across Live and Asynchronous Modalities

We found that students often participated in course learning activities across several modalities including both asynchronous and synchronous forms. This led to some interesting phenomena which we describe in the following sections. First, we discuss how the use of both asynchronous and synchronous media enables MOOCs to adopt a pedagogical structure similar to that of the flipped classroom. Next we describe how participation in asynchronous modalities often drives discussion in live activities.

4.5.3.1 Live Media: Flipping the MOOC

In recent years, the *flipped classroom* has emerged as a popular pedagogical method that prescribes performing interactive group learning activities inside the classroom while conducting individual instruction outside the classroom [134]. The flipped classroom pedagogy represents a combination of constructivist collaborative learning theory with direct instruction methods. Early evidence suggests that flipped classrooms are perceived positively by students and lead to better student performance [134].

We observe that in both the web development and poetry courses, a similar paradigm is being established. Students engage in individual learning activities offline, i.e. they watch lectures, read poems, and write essays. Then students and instructors come together for more participatory learning activities using synchronous communication modalities. Students engage in pair programming

and discussion in the web development course, and, in the poetry course, participants read poems again and discuss them. Thus, we argue that Live MOOCs are able to adopt an analogous structure to that of the flipped classroom: students complete independent learning activities on their own time and then come together to participate in collaborative learning activities during live sessions. Like in the classroom, in a MOOC, the times when the students and the instructors can all come together are valuable, thus they should be used for valuable collaborative learning activities.

4.5.3.2 Asynchronous Driving the Live Conversation

We note that asynchronous forms also have an important role to play in courses employing live learning experiences. In prior work, asynchronous media, such as wikis, blogs, and forums, have been shown to support student reflection and discussion [104]. Indeed, we see in both courses that students engage in ongoing discussion about the course and its content in the discussion forums. PT2 noted that the discussion happening in the asynchronous forums had a direct impact on subsequent live activities. PT2 reported "students drive the content, and the hot topics in the discussion forums in the class each week are discussed during the webcast and through all the interactive channels we have." WDI also reported that topics students brought up in the course forums would become topics of conversation during live Q&A sessions. In this way, asynchronous communication modalities, like forums, provide a channel for reflective discussion, which can then develop context for future live learning activities.

4.5.4 Supporting Different Kinds of Participation through Various Live Modalities

In the online poetry course, we observed that the webcast includes a wide variety of synchronous communication modalities that students can use to participate in the discussion. Those modalities include calling in on the phone, leaving a voicemail, commenting on Facebook Live stream, tweeting, or posting on the course forum. PC explained that incorporating all of these modalities is by design:

> What's so great about that is the webcast is this kind of catch all that enables us to have a whole bunch of, a whole range of levels of participation, a bunch of ways that

people can engage with us.

Having all of these modalities not only provides the opportunity to participate, but also enables students to make choices about how they want to participate. If a student wants to make a vocal contribution, heard by all participants, they can call in on the phone. If a different student wants to participate in a more peripheral way, they can participate in the Facebook chat. By providing this spectrum of modalities, the webcasts enable students to participate in a way that suits them.

In their work investigating participation in live experiences, Hamilton et al. find that incorporating hot, i.e. higher fidelity, participation modalities provides engaged viewers' with more impactful ways to participate in live experiences [75]. Similarly, in this work, we observe that highly engaged students participate through hot modalities. PC explained that she often notices more active students calling in to the webcast:

> I'll recognize them from the forums, because the people that call in are often people who are active in the site as well. So it's kind of a correlation between your level of participation in the site and also your level of participation in the webcast.

In this way, increased participation in peripheral modalities may lead to participation through more impactful, hot modalities, when available. Prior research has investigated how students have different learning styles and has prescribed supporting alternative learning activities to meet student needs [135]. Similarly, providing a variety of communication modalities for live learning activities may better support the participatory learning needs of students.

4.5.5 Open Problems for Live MOOCs

We discuss some open problems around the use of live media in MOOCs. First, we discuss how we observed small groups of learners forming and some of the resulting issues. Scaling participation in live learning activities was another recurring issue in the MOOCs we observed. Finally, to address the issue of scaling, participants reported considering differentiating live learning experiences for students based on whether or not they paid to take the course. We discuss some of the issues around this approach for open online courses.

4.5.5.1 Organizing Learner Groups

While live small group learning experiences enable students to connect by doing work together, organizing these meet-ups and work sessions is a non-trivial problem. Instructors in both courses explained that to an extent, students would organize their own small groups. In the web development course, WDI explained that "students kind of self sort into groups, and they sort of tend to pair program with different people in their group once the groups are formed." PT1 reported similar organization in the poetry course:

> The students sort of self sort early on in the course. We have a section for them to create their own study groups and reading groups and you'll see a San Francisco reading group, New York reading group. They already know each other in a way before hand.

In both courses, students would organize into groups usually through the course's discussion forum. Often these groups formed around a shared geographic or cultural background. These groups then became a resource for later organizing small group learning activities like pair programming and poetry reading.

However, not all students found their way into one of these groups. Several of the web development students we interviewed reported having difficulty finding others to do pair programming sessions with. To find pair programming partners, students reported soliciting partners on the course's Slack and Gitter chat channels, with some success. Additionally, the course's external website enables students to look for partners or advertise their availability for pair programming. Using the site, students could setup pair programming events at times they were available, or search for other students who were also available at those times.

One issue that emerged around this style of ad hoc organization of pair programming sessions was that students often found themselves in pair programming sessions with people that had a significantly different skill level than themselves. Many of the students that we interviewed reported participating in pair programming sessions, where they were matched with someone with more

expertise than themselves. In these cases, the more experienced partner would usually take on the role of mentoring the other, showing him/her the ropes and guiding them through the process. WD3 recalled his first pair programming experience,

> The first one I hadn't done the introduction to the course. I didn't even read the instructions [on how] to do the pair programming so I had no clue what we were doing in the session. I got into the session with this guy, he knew exactly what to do and the communication was excellent. It was more him teaching me things than we getting the stuff done. During that first hangout, I was more the apprentice, and he was the teacher. I learned about how things need to be done, the working environments and how fast you have to be to get the other involved in what you are doing.

Despite the significant difference in skill between the two participants, it was still a rewarding experience for WD3. It is unclear how more experienced students view these interactions. However, in the cases participants reported, skilled students seemed willing to do this mentoring work.

It is clear that there is a need for future work examining how to support the formation of student groups in online courses. Prior work has found that grouping students by order of arrival (i.e. random selection) led to the formation of geographically and culturally diverse groups of students [128]. They found that student engagement in diverse groups led to better student performance in courses and led students to develop new perspectives. However, future work could also explore methods of pairing or grouping students while accounting for cultural background and skill level, which may help form more cohesive student groups.

4.5.5.2 Scaling Courses without Sacrificing Social Participation

A core problem for MOOC instructors is how to manage the scale of their courses, which may have tens of thousands of students. Instructors cannot attend to every aspect of the course for every student. Potential solutions include automating different aspects of the course's curriculum, such as student assignment evaluation and feedback. Regarding evaluation of student pair programming

sessions at scale, WDI explained:

> I think it is a fascinating question of whether or not that checking step could be automated. Because at the end of the day... Our first order concern is are the students really trying it, and are they sort of following the correct protocol, when they try it?

However, increasing automation to support increasing the scale of courses runs the risk of depersonalizing courses. Automation of learning activities may lead to less social engagement. When discussing the issue with PT2, he explained his concerns regarding Coursera's design, saying:

> A lot of the tools favor that kind of operation. It's actually more difficult [in] Coursera, at least currently. It's more difficult to be personal with students than it is to be impersonal with students. There's more tools to make it more automated than tools to make it not automated, now that I think about it.

The poetry course's team has developed tools and practices for conducting participatory live discussions in their course. However, the Coursera platform itself doesn't necessarily support their needs. PI explained that they have "fought consistently to try to use creative options so that discussion and conversation and subjective responses to the material are allowed."

There is a definite need for MOOC platforms and third party sites to incorporate tools that help instructors conduct, organize, and scale participatory live experiences like the online poetry course's webcast or the web development course's pair programming experiences. Additionally, in both courses, instructors relied on TAs or involved students to engage and facilitate student participation. Approaches that distribute some of the human work of facilitating participation to students, i.e. learnersourcing [136], might help scale courses while still engaging students.

4.5.5.3 Differentiating Live Experiences for Paid Students

One approach that instructors thought may alleviate scaling issues involved differentiating course live experiences between those students who have paid to take the course and those who haven't. Within the MOOC platforms there has been a movement to start offering certificates,

which verify that students participated in and completed the course. Both courses that we investigated offer the opportunity for students to receive course certificates. In the web development course, students who wish to earn a certificate must pay a fee of 99 USD to be eligible. The online poetry course offers their certificate for 49 USD.

When we discussed the issue of scaling participation, WDI indicated that they were considering only offering the live Q/A and pair programming sessions for paid students. As discussed earlier, the pair programming experiences of students vary, with students potentially being matched with less capable or committed partners. WDI hypothesized that this issue may be mitigated if the pair programming exercises were limited to students who had paid for the course certificate:

> There is some level of commitment implied by somebody putting money up front to take a course. Those students are more likely to stick with it, their completion rates are better. [...] So you know, rather than trying to solve the problem at scale, we were going to see how much of the problem kind of goes away by itself if we focus on doing those activities inside the smaller paid cohorts.

Requiring students to pay in order to participate in the course's live experience may raise the overall quality of those experiences. However, it puts a significant barrier to entry on the course's potentially more beneficial learning activities, reducing its overall openness. The online poetry course's staff expressed a different outlook on managing participation in their course. When we were discussing the design of Coursera, PC explained how the platform's focus on students working towards the certificate didn't match with their intent for the course:

> We never want people to pay for the course... because so many learners are just in it for fun, like they don't actually really care about the certificate [...] But the platform, as it was, was really set up to reward the people who are going for the certificate. There's all these milestones and these completion things and all this encouragement of "get this and you'll get your certificate" but for us that wasn't really important. It was really more about how do we encourage meaningful, thoughtful discussion? How

> can we can encourage people to peer review each other's essays without feeling like they had to because they paid? You know what I mean? If for example they decide to move to a system where all courses are you pay for everything, that would probably be a little bit of a deal breaker for us because we don't run this course because we want people to pay for it.

The time of instructors is inherently valuable, and paid versions of courses may enable instructors to spend more time interacting with students. Future work should examine if there are other approaches for identifying and supporting more engaged students, without relying on paid differentiation. Alternatively, approaches that foster independent live student-student learning activities, like pair programming, may reduce the overall demand on instructors' attention. Further, there is a need to investigate how differentiating participatory live experiences for paid versus non-paid students impacts the development of course communities and learning outcomes.

4.6 Conclusion

Online education, particularly through the emergence of MOOCs, is seeking to expand in reach and scale. However, developing participatory learning communities in online courses, which are vital to their success, is non-trivial. Evidence suggests that using asynchronous media alone to support student engagement is not enough.

We observed some MOOC instructors, who are incorporating live media in their courses, in order to integrally provide participatory learning experiences for their students. We found that live participatory learning experiences often took the form of real-time discussion and collaborative work on student assignments. We also found that incorporating live media learning activities enabled the development of course community through extended engagement and legitimate peripheral participation. In the poetry course, the webcast live media space served as a place for the course community, connecting participants' various social and cultural contexts.

Incorporating multiple modalities, both synchronous and asynchronous, led to new participatory learning experiences. For example, the incorporation of live media in online courses enabled

the adoption of an online flipped classroom paradigm. Students worked independently, using asynchronous modalities, then came together, using live modalities, to participate in real-time learning activities. The availability of complementary modalities enables students to make decisions about how they wanted to participate, providing options to suit their various learning needs.

It is clear that Live MOOCs, and the media spaces they employ, function as complex ecosystems of human actors, digital media, ideas, and physical spaces. In the two courses of the present study, one in the humanities and one in computer science, we observed live media's potential for supporting vibrant participatory learning in online course communities. At the same time, there is much new work to be done to support the organization and management of MOOC media spaces to help instructors more effectively encourage and moderate student engagement. Additionally, issues recur regarding how to support these communities at scale. How do we enable students to connect with small groups, in which they identify and work well, within the contexts of massive courses? How can we provide best opportunities to participate in social learning activities to increasingly large groups of students? In future work, we aim to further explore these questions and begin to design media tools that help course participants address the needs of their learning communities, across a range of scales.

5. RIVULET: EXPLORING PARTICIPATION IN LIVE EVENTS THROUGH MULTI-STREAM EXPERIENCES*

During the past decade, live streaming has emerged as a new form of participatory social media. Live streaming has come to refer to live, streaming, video as well as a set of communication media that enable viewers to interact with each other and the streamer. We attribute the emerging popularity of live streams to their ability to enable remote viewers to engage and participate in shared live experiences (Chapter 3).

The typical live streaming experience consists of a streamer broadcasting a single video stream accompanied by a dedicated chat channel. However, multiple, simultaneous, live streams provide an interesting opportunity to experience events. For example, on Periscope multiple streamers commonly stream simultaneously or within minutes of each other while attending events like concerts or conventions [35]. Similarly, on Twitch, streamers frequently play games together, while they both broadcast independent streams and their viewers' chat in separate chat channels.

Despite this trend there is minimal support for identifying and participating in these multi-stream experiences. There are a number of 3rd party sites that support embedding multiple live streams together, but do not provide much support beyond the visual aggregation of live streams and their separate chat channels. There are a number of research projects looking at combining multiple live streams [137, 138, 50, 81, 42, 53, 55, 139, 140], but these do not examine audience participation and the resulting experiences.

In this work, we explore how to support communication and participation in multi-stream experiences. In particular, we are interested in the following research questions.

*Edited reprint with permission from "Rivulet: Exploring Participation in Live Events through Multi-Stream Experiences" by William A. Hamilton, John Tang, Gina Venolia, Kori Inkpen, Jakob Zillner, and Derek Huang, 2016. In *Proceedings of the ACM International Conference on Interactive Experiences for TV and Online Video*, 31-42, DOI: https://doi.org/10.1145/2932206.2932211. Copyright 2016 by Hamilton, Tang, Venolia, Inkpen, Zillner, and Huang. Publication rights licensed to ACM.

1. How will people experience a collection of streams coming from a live event?

2. How will people use new and existing communication modalities to participate across different streams that are part of an event?

We designed and prototyped Rivulet, an end-to-end mobile live streaming system for multi-stream experiences, as a technology probe for investigating these questions [33]. Rivulet incorporates common live stream modalities including live video, text chat, and hearts (as seen in Periscope). However, we extended these modalities to specifically support a more integrated multi-stream experience, for example all of the streams share an event-wide chat channel. Rivulet also enabled us to explore push-to-talk (PTT) audio from any viewer to the stream, a higher fidelity communication modality that we hypothesized might be more engaging for participants.

To observe and explore realistic participation in multi-stream experiences through Rivulet, we conducted an at-scale field study with eight local Periscope streamers who streamed a local music event. Four participants streamed the event using Rivulet while the other four streamed the event using Periscope. We also recruited 226 viewers on Mechanical Turk to watch live on both Rivulet and Periscope. This led to a brief, but realistic, multi-stream experience.

We found that by aggregating multiple streams together Rivulet helped participants find interesting streams to watch and participate in. It also afforded new engaging live experiences for viewers and streamers, engendered a stronger sense of community, and helped participants better understand what was happening at the event as a whole. Finally, despite some technical issues, PTT audio proved to be an engaging communication modality, which afforded unique participatory opportunities for viewers.

We first present the motivations and a detailed description of Rivulet's design. Next, we present the design of our field study of Rivulet along with the results of the study and a discussion of their implications for the design of live streaming experiences.

Figure 5.1: A screenshot of the Rivulet viewer client during the Jazz Walk study. Viewers could focus on and listen to one stream at a time and see previews of the other live streams. Viewers shared an event-wide chat with usernames color coded by the stream they were watching. Viewers could send hearts to their focused stream, and see hearts sent to any stream. Viewers could send push-to-talk audio to their focused stream by clicking on the microphone icon in the upper right of the live stream. Reprinted from [75].

5.1 Rivulet Prototype

The Rivulet prototype implements an end-to-end live streaming service. The prototype consists of a custom Android video streaming application, web based viewer client, and web service. By developing each of these components we were able to design a holistic multi-stream experience aimed at engaging participants through novel communication modalities. We present the design and motivations for each of the components of Rivulet.

5.1.1 Viewer Client

The viewer client (Figure 5.1) was implemented as an online web-based interface. This enabled us to recruit a large group of viewer participants through the web who could use the system by simply navigating to a URL. The client enables participants to watch multiple streams simulta-

neously, engage in a global chat, give feedback in the form of hearts to streamers, and broadcast PTT audio.

5.1.2 Broadcaster Client

We developed a custom Android application that enabled streamers to broadcast video from either the front- or back- facing camera (see Figure 5.2). Participants could also rotate the orientation of their phones while streaming as the viewing client dynamically rotated the streaming video for viewers. Video was broadcast at a resolution of 576 x 320 (the same resolution used by Periscope) and was encoded at a data rate between 1.5 - 2.0 Mbps using H.264. The encoded video was streamed to a cloud based Wowza streaming engine server using the Real Time Messaging Protocol (RTMP). During the course of the presented study, video was uploaded over cellular LTE connections. We will describe how the broadcaster interface integrates each of the explored communication modalities in the following sections.

5.1.3 Supporting Multi-Stream Experiences

To support participants in watching and participating in multiple streams, they first needed to be able see them all and choose which one to focus on. While viewers could see a live preview of all of the active streams in the experience, they could only focus on one. The focused stream appears in the middle of the interface and audio plays for that stream (see Figure 5.1). Previews of other streams appear smaller and darkened on the right side of the interface. To focus on another stream, viewers simply click on a preview to swap its place with the currently focused stream in the interface. At the same time, the new stream's audio is played instead of the previously focused stream's audio. As streams started and stopped broadcasting, they were dynamically added to and removed from the interface. When the client is first opened, and if the stream that the viewer is focused on ends, the system randomly selects a stream to play.

Each stream is labeled with the name of the streamer as well as a fraction indicating the portion of all viewers of the event who are watching this stream. We intended this to help viewers understand how other viewers were selecting which stream to watch. This fraction also shows the

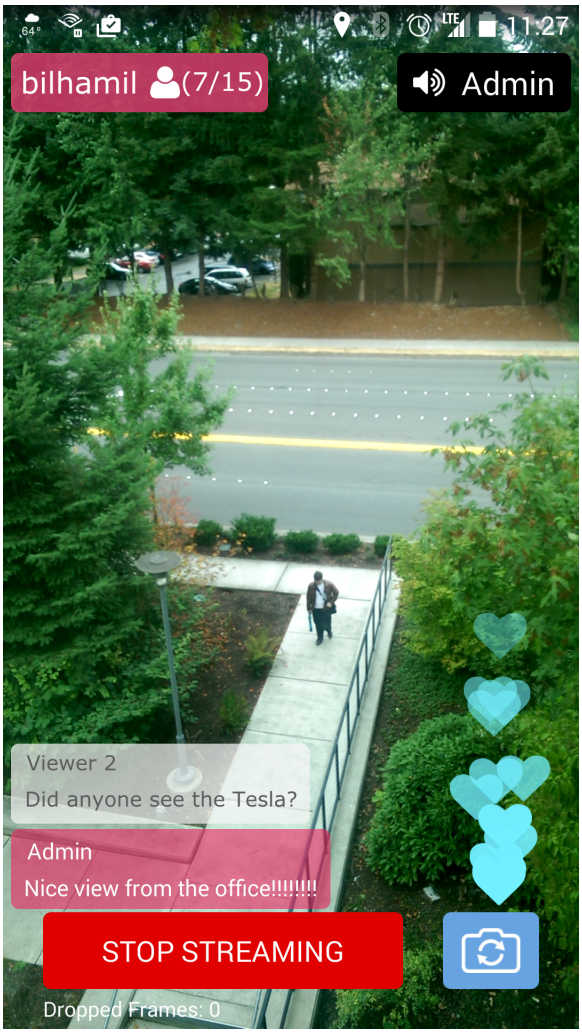

Figure 5.2: A screenshot of the Rivulet mobile client. The mobile client enabled sharing live video and audio and monitoring viewers, hearts, chat, and PTT audio. Reprinted from [75].

streamer how many viewers are watching them compared to participating in the event as a whole (see Figure 5.2). Additionally, each stream is algorithmically assigned a unique color, which is helps differentiate each stream's viewers in the global chat.

We used a custom Adobe Flash Player to stream and render each video stream. The total delay from broadcaster to viewer was typically between 2 and 5 seconds, which is equal to or less than most current live streaming platforms. While viewers could watch each of the streams, streamers were unable to see other live streams during the study. While streamers could not directly maintain awareness of other streams, they would be indirectly aware through viewers' comments in the

provided communication modalities.

5.1.4 Event-Wide Text Chat

Our second research question focuses on how to participants experience communication modalities in multi-stream environments. We were particularly interested in how to support viewers using text chat in a multi-stream experience. Rivulet associates all of an event's live streams with a single event-wide text chat. This differs from associating a single stream with its own text chat, as seen on Twitch, Periscope, Meerkat, and many other streaming platforms. We expected that participants would discuss and experience the event as a whole instead of in disjointed conversations around each stream. However, we still wanted participants to be able to make comments localized to particular streams and make sense of who was watching what stream. In the chat, viewers' usernames were color coded with the live stream they were watching when they made the comment. Similarly, we hypothesized, for streamers, text chat from viewers focused on their stream would have more immediate value than chats from other viewers. Thus, while all text chats would briefly appear on the streaming interface, chats from the streamer's viewers would be highlighted with the color associated with their stream (see Figure 5.2). Chats from viewers of other streams appeared with a gray background.

5.1.5 Hearts

For the Rivulet prototype, we adopted the hearts communication modality featured in Periscope. Hearts are an ephemeral mechanism that enable users to send lightweight feedback to streamers. A viewer simply clicks on the stream to send one heart, which appears on the video stream and briefly floats up before disappearing. This can be done rapidly, and often is, to send a stream of hearts. To help viewers maintain awareness of each stream, viewers can see hearts appearing on each stream separately (see Figure 5.1). Hearts are roughly color coordinated with viewers. While the heart shape implies love, their exact meaning is ambiguous. Hearts are an interesting emerging communication modality because they provide extremely ephemeral and localized feedback about a live stream. They provide quick, positive feedback to the streamer about their viewers. However, taken

beyond the context of just one stream, hearts might help other viewers identify interesting activity in a multi-stream environment. Considering hearts within the framework of hot and cool media, they are extremely cool. They are very low fidelity in that they only have one particular form. At the same time they afford ample opportunity for participation, as any number of participants can send as many hearts as they wish at any point in time without being clearly identified.

5.1.6 Push-To-Talk Audio

Our goal with the incorporation of PTT audio was to further explore our second research question by examining how participants engage in a multi-stream experience using a relatively novel communication modality. The PTT modality is not common to live streaming practice and lies somewhere between cool text chat and hot live video on McLuhan's spectrum. We designed PTT to afford viewers a higher level of impact on the experience, while affording more opportunity to participate than live video.

In Rivulet, any viewer with a microphone can broadcast audio on the stream they are currently focused on by clicking and holding on the microphone icon displayed on the stream (see Figure 5.1). The audio is captured and encoded in the browser, streamed to the Rivulet web service, and then pushed to the streamer's broadcasting client. On the mobile client, the audio is played back immediately to the streamer and also mixed into the right channel of the outgoing stream's stereo audio. This allowed viewers of that stream to hear PTT audio from other viewers in sync with when the streamer heard it. An indicator appeared in the video stream during showing who was talking (see PTTs from AJBBB and Sweet in Figure 5.1). This indicator was also displayed on the broadcaster client (see PTT from Admin in Figure 5.2). To prevent feeding the PTT back to the person who spoke it, they heard only the left channel from the video stream for the duration of the PTT. Streamers wore headphones to prevent PTT audio from leaking into the left channel of the broadcast.

We limited PTT broadcasting to only one viewer at a time per stream. We also set a maximum of 10 seconds for PTTs to prevent any viewer from dominating the modality by continuously broadcasting. The system also ensures a 5 second break between every PTT to give the streamer a

chance to respond. When a viewer tries to start a PTT, if the channel is clear, a start chime is played and a 10 second countdown starts. After 10 seconds, if the viewer has not stopped broadcasting the system plays a disconnect chime and stops the transmission. If the viewer tries to PTT when the channel is not clear, they see a wait signal until it is clear. If multiple viewers are trying to PTT simultaneously, the system places them into a wait queue.

We explicitly intended PTT to be a communication modality at the single stream level. Only viewers of a particular stream would be able to hear PTTs sent to that stream. We also expected PTT to be easier for streamers to pay attention to while still engaging in the shared event, since they did not have to look at their device to perceive the incoming audio.

5.2 Study Design

We designed a study of Rivulet to explore our research questions around communication modalities and emergent behaviors in multi-stream experiences. Through the study, we aimed to create a multi-stream experience that was as ecologically valid as possible. To this end, we recruited experienced streamers to broadcast at a local event to an audience of live viewers. We also worked to recruit an online audience of reasonable scale. In the following sections, we describe our process for selecting and organizing an event, recruiting participants, and evaluating the experience.

5.2.1 The Jazz Walk Event

We wanted to find an event which would be interesting to the streamers and viewers and had multiple concurrent activities to provide ample opportunity for streamers to share different perspectives of the event. We also had to consider the availability of robust cellular network connections as a prior study failed due to cellular network issues. We chose a local jazz festival called The North City Jazz Walk, which historically attracts several hundred attendees. The event featured 10 local musical groups playing in different venues across a 3 block area. Venues included bars, parking lots, a coffee shop, a church, and a club house.

5.2.2 Live Streamers

Prior to the event, we recruited local Periscope streamers. By recruiting experienced streamers, we aimed to have participants who were comfortable conducting a live stream and interacting with viewers. We also expected that streamers would be able to provide insights into how their experience with Rivulet compared with Periscope. We identified local Periscope streamers by collecting geocoded Periscope Tweets from the local area over a four-day period. From the resulting 250 streamers, we were able to contact approximately 50. We also asked these streamers to forward the study information to any local streamers they knew. We successfully recruited 7 participants to attend the Jazz Walk and added one personal contact who was familiar with live streaming. Participants were offered a 250 USD gratuity for taking part in the study.

Prior to the study, we met the streamer participants outside the event area where we administered a short pre-questionnaire and divided the participants into two groups of four. Four participants were asked to stream using Periscope [P1-P4], the other four were asked to use Rivulet [R1-R4]. The Rivulet streamers were given a brief tutorial on how the system worked. While the Periscope streamers used their own devices, we gave the Rivulet participants Android phones to use during the study. We asked that participants attend the event for approximately an hour and a half and that they stream for at least a quarter of the time. The Periscope streamers were asked to publish a tweet with the hashtag #MSRJazzWalk anytime they started streaming, so they could be found. We placed no other restrictions on what or how they streamed. We only asked that they do what they would normally do. During the study, a researcher was available at the event for technical assistance. After the study, we met with the streamers again and briefly discussed the experience and asked them to complete a short survey.

5.2.3 Mechanical Turk Viewers

We aimed to recruit an audience of reasonable scale to observe during the study. We argue that this is critical for observing meaningful engagement and communication during a live streaming experience. Thus, we recruited viewer participants through Amazon's Mechanical Turk. Approxi-

Table 5.1: Summary of Likert questions asked in each study condition. Note that Q4 was only asked in the Rivulet condition. Reprinted from [75].

	Likert Questions
Q1	I was aware of all the streams offered by the people streaming at the Jazz Walk today.
Q2	I enjoyed being able to choose different streams at the Jazz Walk.
Q3	I was aware of what the other streamers at the Jazz Walk were covering compared to what I was watching.
Q4	I felt like I was able to influence the live streams using the push-to-talk feature.
Q5	I felt like I was able to influence the live streams using text chat messages.
Q6	I felt like I was able to influence the live streams by sending hearts.
Q7	I was able to easily find a view that was interesting to watch.
Q8	Using [Periscope, this Prototype] to view the Jazz Walk event was fun.
Q9	I felt like I was part of a community of people enjoying the Jazz Walk.
Q10	I felt connected to the people streaming the the Jazz Walk.
Q11	I felt connected to the other people viewing the Jazz Walk event.
Q12	I felt like I could control what I viewed of the Jazz Walk event.

mately 15 minutes after sending the streamer participants into the event, we published two Human Intelligence Tasks (HITs): one to recruit viewers to watch the experience on Rivulet, and the other for Periscope.

Participants in both conditions were shown a brief video explaining how either Rivulet or Periscope worked. Viewers were also given a link to the Jazz Walk website. Rivulet participants were directed to the viewer client through a link. Since the web-based Periscope client does not afford sending hearts or chats, Periscope participants were asked to use their smart phones (downloading the Twitter and Periscope mobile apps if needed). They were told they could locate streams by searching for #MSRJazzWalk on Twitter.

Participants in both conditions were asked to watch streams for at least 20 minutes and as long as they liked beyond that. After watching, participants in both conditions were asked to fill out a short questionnaire composed of a series of Likert questions (see Table 5.1). We also

asked participants to rate the usefulness of the communication modalities in each condition using a semantic differential and answer a series of open-ended questions. We expected that viewer participants would be engaged in the task between 35 minutes to an hour. Thus, participants in each condition were offered an 8 USD compensation (in keeping with a 10 USD hourly wage). 120 HITs were published for each condition.

5.2.4 Data Logging

Besides serving the page content and managing real-time messaging, the Rivulet web server also logged user actions and relevant metadata in a database for later analysis. We were not able to log periscope user interactions, so we are not able to present a quantitative analysis comparing conditions.

5.3 Results and Discussion

Despite the complex nature of the presented study, we experienced relatively few issues, resulting in an engaging and rewarding experience for both streamers and viewers. We present the results of the study and discuss the implications of our findings. We first provide a brief description of the recruited viewership and streams shared during the event. Next, we provide a discussion of how each of the communication modalities were used, and draw implications from our observations. We then discuss how participants engaged in multiple streams and the implications of multi-stream live experiences around events. We also discuss the emergent sense of community we observed. Finally, we discuss implications related to our study design.

5.3.1 Viewership

After publishing the Mechanical Turk HITs, participants quickly flooded into the study. Figure 5.3 illustrates the number of viewers over time in the Rivulet condition. Within 20 minutes over 100 viewers were watching on Rivulet. In total, we had 115 participants in the Rivulet condition [RV1-RV115] and 111 in the Periscope condition.

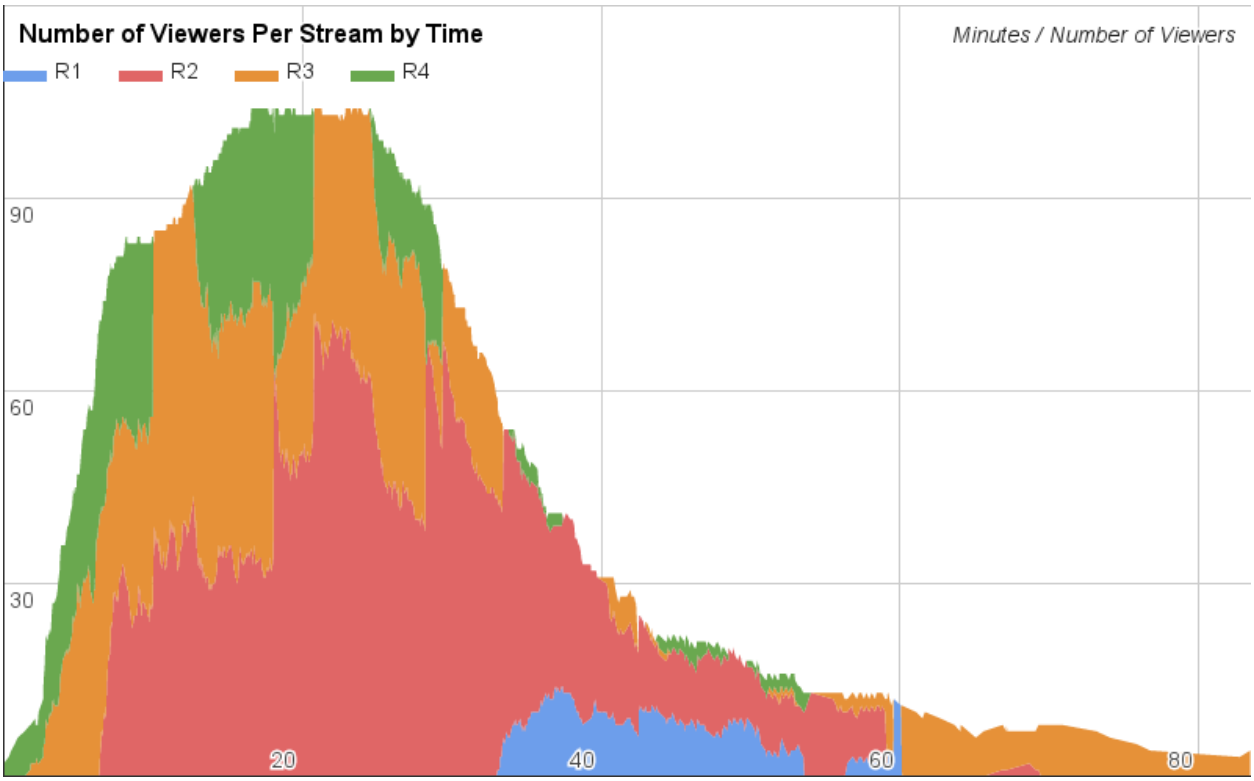

Figure 5.3: Viewers per stream in Rivulet over the course of the study, showing how viewers switched among streams. Reprinted from [75].

5.3.2 Live Streams

During the study, some of the streamers in different conditions decided to stream together. Consequently, there were similar streams in each condition. We provide a brief description of what was streamed by each of the streamers.

R2, P2, and P3 were a group of high school boys and were friends prior to the study. They walked and talked together while simultaneously streaming 3 different streams almost continuously for the duration of the study. Before entering the event, they first went to a nearby grocery store and purchased some rice cakes and water. This proved to be a fairly humorous diversion for many viewers. They then started walking around the event and stopped at several different musical performances. While they walked they focused on interacting with their viewers and with each other. R2's stream received the most chat messages per minute and the second most PTTs per

minute.

P1 and R3 are a brother and sister in their thirties. For most of the study they streamed from a bar that was hosting one of the musical performances, later walking to another bar hosting a performance. They used their front-facing cameras for much of their streams to interact with their viewers with less focus on the jazz performances. R3 throughout the study made humorous faces and noises trying to get a reaction from her viewers. At one point, she started encouraging viewers to tell jokes on her stream. She also pretended to eat the hearts viewers were sending her. P1's stream was more subdued, and he streamed both the musical performances and himself while he interacted with viewers. P1 and R3 frequently interacted with and streamed each other during the study.

R1 and P4 were two men in their early twenties and were friends prior to the study. During the study they streamed at different outdoor performances and while walking between performances. They interacted with their viewers to a much lesser degree than the aforementioned streamers. At one point the pair got up and started dancing while a band played a cover of the Peanuts' theme song. While P4 streamed for most of the duration of the study, R1 only streamed for a short duration toward the end of the event.

R4 was by himself for most of the study. He frequently responded to viewer chats, but generally his stream focused on the musical performances at the event. He never showed his face on stream during the study, and often just streamed different performances. At one point, he did stream himself walking down the street, but minimal interaction occurred with viewers during this time.

5.3.3 Text Chat

During the study, a total of 862 chat messages were sent among the Rivulet viewers, and all but 17 of our 115 Rivulet viewers sent at least one chat message. Figure 5.4 illustrates the distribution of viewers based on how frequently they chatted. As may be expected given the tendencies of lurkers [141], a large number of viewers, 87 out of 115, chatted either not at all or less than twice every five minutes. However, the remaining 28 viewers chatted regularly, one as often as 3 times a minute.

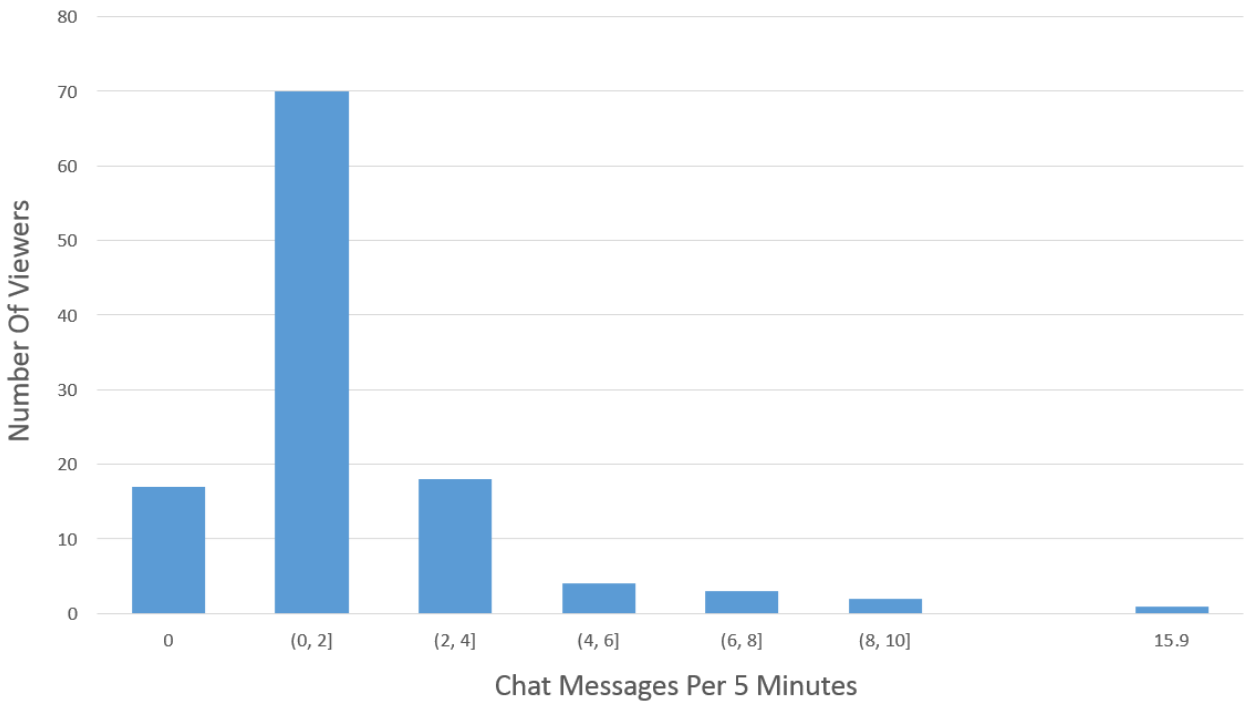

Figure 5.4: Distribution of chat frequency among viewers. Reprinted from [75].

Chat messages were of varying content including comments and questions about the event directed at the streamer or other viewers. Some viewers and streamers reported that at some points the chat was moving too fast for them to effectively read every message, a known issue within large live streaming chat channels [48]. We conducted a coding analysis of chat messages to build an understanding of the conversation. Codes emerged through the analysis relative to our research questions. The most common codes included viewer responses to other participants (13.8%), commentary on the experience (13.6%), discussing the prototype (13.6%), viewer reactions to events (10.9%), and questions about the experience (9.7%). Interestingly, viewers often made requests (7.4%) of the streamers via text chat suggesting how they should stream or participate in the event:

> *Turn the phone sideways* RV71, to R1.
>
> *Go to the nearest venue!* RV72, to R2.
>
> *haha...[R3], somebody else is livestreaming at the same venue as you, you should find them!!!!* RV94, to R3.

Can you ask him where he got that hat? RV108, to R4.

These requests illustrate the level of engagement some viewers had with the streamers in shaping how the event was covered. It even included coordination among the streamers, as viewers recognized other streamers at the event.

5.3.3.1 Understanding Event-Wide Text Chat

We were particularly interested in evaluating how participants understood the global text chat and its impact on the experience. Many viewers indicated that, while they were able to understand which viewers were watching each stream, it was confusing. Many viewers also expressed wanting to see only chats from viewers on the same stream or at least be able to filter out chats from other streams. When asked to rate the usefulness of the text chat modality, 90% of viewers responded positively in the post questionnaire that being able to see chat messages from the same stream they were watching was useful, only 57% reported that seeing chat messages from viewers in other streams was useful. The event-wide chat did enable viewers and streamers to maintain awareness of what was going on in other streams. R4 reported he experienced "greater awareness about the event as a whole and what other streamers were doing via event wide chat." While an event-wide chat has clear benefits, viewers and steamers need to be able to quickly identify messages in their active stream.

Despite some initial confusion, 3 of the 4 Rivulet streamers indicated that they could easily understand which chats were coming from their viewers. The binary nature (only 2 colors) of the chat visualization on the broadcasting client (Figure 5.2) made it easier to understand which chats were coming from viewers of their stream.

5.3.4 Push-To-Talk Enables High Profile Participation

PTT was used by significantly fewer viewers than text chat. Only 14 out of the 115 recruited viewers attempted to broadcast audio. Furthermore, 50% of the messages failed to be understood by the streamer or viewers. This was due to a number of issues including viewers' microphone configurations, the system prematurely cutting off participants' audio, or the audio being too quiet

to hear. Since the Jazz Walk was a live music event, the ambient noise level at the event frequently drowned out incoming PTT audio.

For the half (42 out of 83) of the PTT messages that were comprehensible, messages ranged from asking questions, making jokes, commenting on the stream, asking if the speaker could be heard, or simply saying "Hi!". In several instances a streamer and viewer were able to have a short conversation through the stream audio and PTT. Unlike chat, PTTs were mostly directed at the streamer, not other viewers.

When asked what they liked about PTT, many viewers indicated that they liked the instant, high profile communication with the streamer. According to RV18: "It's loud and heard, so it's easily recognizable. It would be easy to make a point that stands out above the wall of text." Other viewers seemed to appreciate others' use of PTT. RV45 indicated that: "While I did not personally use it, listening to other people interact with the streamer was neat. Being able to influence their decision making was the best part."

Other viewers had concerns about the value of PTT. RV63 felt like PTT would "just encourage people to act out", and R3 indicated that she would like the option to mute particular viewers who were trolling her. While we did not explore this issue directly, there is a clear need to support boundaries of use for such a high-impact communication modality.

We transcribed and coded PTT messages for content and to whom they were directed. This revealed that PTT messages were integrated into the conversation in the stream where almost all messages either clearly implied a response from the streamer, or were in direct response to the streamer. This is in contrast to text chat, which more often was just commentary that did not respond to or imply a response.

While there does not appear to be a direct correlation between the number of chats a user sent and how often they used PTT, 12 of the 14 PTT users were in the top 35% of the most frequent text chatters during the event. This leads us to suspect that PTT appeals to already engaged viewers, who are looking for a more direct means to participate.

Our timing strategy of allowing only 10 seconds of speaking time seemed to keep people from

dominating the channel and gave the streamers an opportunity to respond. None of the streamers indicated that they felt overwhelmed by the incoming audio. We also suspect that PTT audio may be socially intimidating and thus self-regulating. RV34, who sent the third most chats during the experience, but not any PTTs, indicated that s/he was scared to use the feature.

Despite technical issues, the results indicate that PTT audio provided new opportunities for participating in live streaming experiences. PTT proved to be *hotter* than text chat. It is high fidelity and affords a unique means for highly engaged participants to have impact. Furthermore, PTT is cooler than live video, with more space for participation.

5.3.5 Hearts are Noisy

The hearts feature was used extensively in both the Rivulet and Periscope conditions. While we do not have exact numbers for the Periscope streams, a total of 24,523 hearts were sent through Rivulet. While 22 viewers did not send any hearts, 21 viewers sent more than 200 hearts over the duration of the study. Ultimately, we observed it was very easy for the hearts modality to be dominated by a few viewers. For example, one outlier alone sent 8686 hearts.

When we asked Rivulet viewers if they thought hearts were useful to send or see using a five point Likert scale, responses averaged 3.26 (s=1.18) and 3.19 (s=1.32) respectively. Results in the context of Persicope were similar. This lukewarm perception of hearts seems counter-intuitive given the apparent popularity of the feature in Periscope. However, what we did find is that 6 of the 8 streamers thought hearts provided useful feedback to them about their streams (the other 2 were neutral). This leads us to suspect that hearts, at least in their current form, are more meaningful to streamers.

Despite this finding, hearts played a significant role in informing viewers when they should switch streams. RV82 reported that "when people would hit hearts on other streams I would pop over and see what was going on." However, since hearts were so easy to generate in rapid succession, it was easy for one viewer to create a potentially distracting signal with hearts. As RV102 reported "I think the hearts were more the result of someone clicking for no reason than the video's content." Similarly, in the case of R3's stream, when she pretended to eat incoming

Table 5.2: Comparison of selected Likert response means across conditions. 1 = Strongly Disagree and 5 = Strongly Agree. The difference in responses across conditions were analyzed for significance using Mann-Whitney U non-parametric tests with Bonferroni correction applied. Reprinted from [75].

Likert Question	Periscope-μ	Rivulet-μ	Mann-Whitney U	p-value
Q1	3.68	4.21	4320	<.001
Q2	3.45	4.15	3698	<.001
Q7	3.80	4.25	4630	<.001
Q9	3.71	4.10	5059	<.004
Q10	3.60	4.03	4788	<.001
Q11	3.47	4.15	3804	<.001
Q12	3.15	3.83	4081	<.001

hearts, sending hearts became more of a game and less a signal of interesting content. Given the noisy nature of sheer heart throughput, a more valuable signal might be derived by normalizing the number of hearts by the viewer's typical heart sending rate or from the number of unique heart senders at one time.

5.3.6 Viewing Multiple Streams

We found that being able to view multiple live streams and readily switch between them had several immediate impacts on viewers' experience of the event. Drawing from participant responses to Likert questions in the post questionnaire, we found the significant benefits of the Rivulet prototype over Periscope (see Table 5.2). The results for Q1, Q2, Q7, and Q12 indicate that Rivulet effectively enabled participants to watch several live streams simultaneously. We describe the impact of multiple streams through a discussion of how and when viewers switched streams, how viewers were able to find interesting streams to watch, and emergent multi-stream experiences.

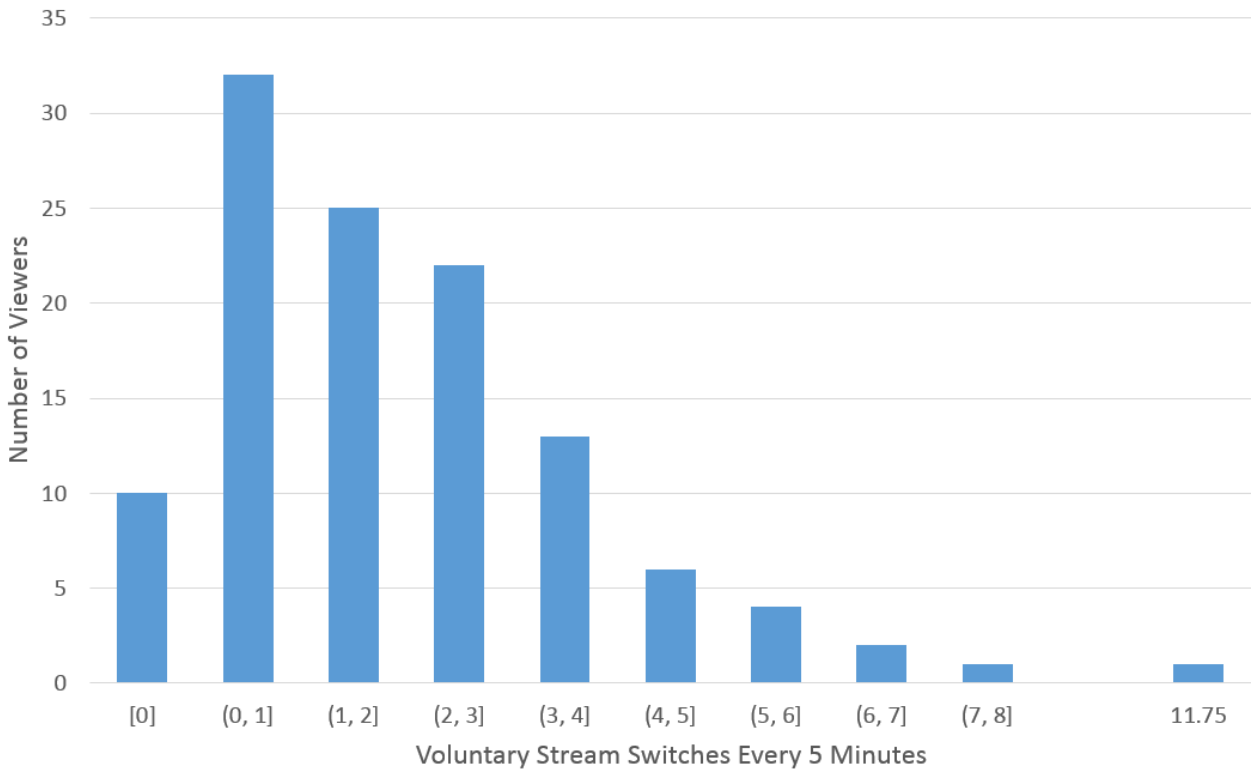

Figure 5.5: Distribution of Viewers by Rate of Stream Switches. Reprinted from [75].

5.3.6.1 Switching Streams

We logged how often participants voluntarily switched between different streams in Rivulet, removing automatic stream switches that occurred when a stream ended. Figure 5.5 shows the distribution of viewers by how often they switched streams. While many viewers switched infrequently or not at all, a significant portion switched streams regularly. On average, 32% of viewers switched streams at least every 2 minutes. One extreme viewer switched streams a total of 42 times. During the first 60 minutes of the study, we observed a diverse distribution of viewers across the streams. As shown in Figure 5.3, viewers actively switched to new streams when they appeared.

Being able to watch and switch between multiple streams enabled viewers to find and participate in streams that were of interest to them. Despite covering the same event, each stream was different in content and activity from the others. R1 and R4 focused more on the musical performances while R2 and R3 focused more discussing the event and interacting with viewers. Different

viewers reported enjoying both of these types of streams and switching streams for an experience that was of most interest to them.

This observation that viewers' personal interests drove their varied viewing behavior is consistent with prior work such as Velt et al. [46] who also explored a music festival. Hamilton et al. [48] also observed that viewers are drawn to certain streams either for their content (such as live music) or to primarily interact with the stream and its community. We argue that by combining different kinds of streams and enabling viewers to explore and participate in them simultaneously, we can support live experiences that are more personally meaningful to individual viewers.

Viewers used a combination of signals to inform switching between the different streams. Many viewers indicated that they switched streams when they saw an interesting conversation occurring in chat. RV66 reported "being able to see the different conversations from the different streams let you know which stream was the hottest at that moment" (hottest meaning most interesting, not McLuhan's hot). Other viewers reported monitoring the live previews to watch for interesting content. RV13 reported "when there was a change of scenery, or when someone changed the camera angle to their face, it made me switch to see what was going on, to hear the audio." Despite the ambiguity of hearts, many viewers reported choosing streams based on heart activity (see Hearts are NoisyHearts are Noisy). Viewers also returned to streams of viewers they had been watching previously. In several cases, we observed viewers exclaiming in chat "[Streamer] is back!" after a streamer restarted their stream.

5.3.6.2 Cross-Stream Experiences

The multi-stream nature of the Rivulet prototype enabled several experiences that viewers noted as exciting. In one case, viewers noticed that R3 and R4 were streaming at the same part of the event and they could see R4 through R3's stream. They pointed out R4 to R3, and one viewer switched over to R4's stream and suggested that he go over and talk to R3. In a similar case, R3 and R2 randomly encountered each other while walking down the sidewalk. They then streamed each other for a while and had a short discussion about the event. RV20 reported that "the most interesting thing that happened while I was watching was when two "hosts" met each other. It was

a little surreal."

We note that without aggregating live streams together, these kinds of cross-stream experiences are virtually impossible in existing platforms. By coordinating streams and communication modalities together around an event, viewers are more aware of stream and can interact across streams.

5.3.7 Sense of Community

Over the course of the experience, it appeared as if a temporary sense of community emerged within the audience of the Rivulet experience. When answering Q9, 94 of the 115 Rivulet viewers agreed (37 strongly agreed) that they felt like they were part of a community. This feeling was significantly greater in Rivulet compared to Periscope (See Table 5.2: Q9).

We also found that viewers in Rivulet felt significantly more connected to the people streaming than those in Periscope (See Table 5.2: Q10), and more connected to other viewers (See Table 2: Q11). Many viewers also indicated in their free responses that they felt they were part of community during the experience. As RV110 said:

> What I liked best was how easy it was for the streamers to interact with viewers and the close-knit feeling that I gained from watching several streams. It felt like I was a part of the community.

5.3.8 Study Design Implications

Recruiting a relatively large number of viewers from Mechanical Turk enabled us to observe a live experience at-scale through the Rivulet prototype. However, given that both streaming and viewing participants were compensated to participate in the event, the study cannot be considered an organically emerging experience. Thus, there are some inherent issues with the ecologic validity of the experience.

For example, while 100% of the participants watched for at least the requisite 20 minutes, only 12 Rivulet viewers watched longer than 30 minutes. It appears that most participants left after the minimum required viewing time in the HIT. By 45 minutes into the study, only about 20

viewers remained, resulting in a relatively short window of time when Rivulet had a reasonably sized audience. Future work could look at different ways to design this kind of study to engender more ecologically valid viewer behavior.

Additionally, looking at the length of streams shared during the study, almost all of the streamers (both on Rivulet and Periscope) were active for most of the study duration. This contrasts to the brief (5-10 minute) streams typically seen on Periscope. It is unclear if this was because they had more viewers than they were accustomed to or they felt like they were expected to because of the study.

We also note that during the study a significant amount of chats mentioned Mechanical Turk (6.7%). While these messages might have distracted from the shared experience, they may also have helped participants connect through their shared experiences on Mechanical Turk. Further work is needed to investigate the social implications of using turkers as participants in live social systems.

5.4 Conclusion

We built and field tested at-scale the Rivulet prototype for experiencing multiple streams of an event. Viewers used all modalities (text chat, PTT, and hearts) to engage with the streamers and with the viewers within and across streams in the event. Their engagement included shaping the way that streamers were covering the event and working to inform other viewers as streams started or stopped. Taken together, we see evidence that multi-stream experiences around events afford new opportunities for participating in and forming impromptu communities. We reflect here on our second research question, namely how people used the various communication modalities in Rivulet on the spectrum of cool to hot media [12].

It is apparent that lightweight, cool signals, like hearts, are a compelling emerging participation modality. While we saw many people engaging through the hearts modality, displaying all those hearts may imply more importance than is warranted. When used in isolated live streams, as in Periscope, hearts may give meaningful feedback to the streamer and viewers. But in the context of multiple streams, people used them as a cue to switch to a stream, only to find out they did not

indicate what they expected. We argue that work needs to be done further refine these types of modalities. For example, visualizing the proportion of people that give hearts, rather than the total number of hearts, may be a more useful signal of which streams are interesting.

Text chat is a warmer communication modality that is used less than hearts. We redesigned text chat as a communication modality to bridge across multiple streams, and foster an event-centric experience. We found that this approach had clear benefits, leading to interesting cross-stream interactions. However, there is a need to more clearly present which chats are from people watching the same stream versus other streams.

Additionally, we found that new modalities like PTT, a modality hotter than text chat and cooler than live video, supported compelling new participatory experiences. While only a small subset of highly engaged users sent PTTs, they engendered a higher level of engagement by immediately responding to or evoking responses from streamers. PTT afforded a new opportunity for higher impact participation. We argue that there is a need for continued investigation of new communication modalities to understand the roles they can play in participatory live experiences.

Finally, with regards to our first research question, we found that multi-stream experiences led to interesting cross-stream interactions. Viewers were excited about encounters involving multiple streamers. They were also able to easily find and participate in streams that addressed their interests and desire for engagement.

We note that we were only able to observe interactions in the context of this one event. Future work could examine multi-stream interactions around different types of events such as parades, conventions, sporting events, political debates, or protests at both larger and smaller scales than what we observed. We expect that different events at different scales will exercise communication modalities in different ways, helping us further learn how to support participation in multi-stream events. Rivulet also did not explore streamer-to-streamer communication, which could become more important in events with more streams. As live streaming continues to evolve and practices emerge, we believe that supporting interaction among multiple streams from the same event is an important, new form of social media communication that is ripe for future work.

6. COLLABORATIVE LIVE MEDIA CURATION: SHARED CONTEXT FOR PARTICIPATION IN ONLINE LEARNING*

In this chapter, we work to addresses the need for shared context [142, 143] and participation [13, 144] in online learning experiences by synthesizing two recent forms of new media—live streaming [48, 35] and free-form web curation (FFWC) [36, 37]—to create the new form of *collaborative live media curation (CLMC)*. In recent years, massive open online courses (MOOCs) have expanded the reach and scale of education. There has also been an emergence of small private online courses (SPOCs), which rely more on small group learning experiences [145, 146]. Both MOOCs and SPOCs draw on prior media, including asynchronous forms, such as pre-recorded YouTube lectures [124] and student discussion forums [125]. As we observed in Chapter 4, some are starting to also employ synchronous media tools, like chat rooms and Google Hangouts to engage students in participatory learning experiences. Further, research in communication has shown the importance of shared visual context for conversational grounding in collaborative tasks and distance learning [142, 143]. To address these needs, we develop a new medium for creating online contexts for participatory learning experiences.

We incorporate live streaming, an emerging form of social media, because it has been found to afford sharing rich experiences and participating in them (Chapter 3). Platforms such as Twitch (Chapter 3), Periscope [35], and Facebook Live [49] have enabled new live streaming practices. These platforms combine streaming audio/video of live action with other synchronous and asynchronous communication modalities. This combination of modalities has been shown to provide shared context, which supports online community formation (Chapter 3).

We build on the the medium of free-form web curation, which has been show to help stu-

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dents engage in visual thinking [36] and creatively engage with prior work to conceive, synthesize, and express new ideas [37]. In art, curation means the creative conceptualization and design of an exhibition context [147]. Curators arrange and interpret elements in an exhibition space, to stimulate active engagement and produce cultural meaning. *Free-form web curation* is a computational medium that enables multimedia elements to be spontaneously collected from the web, written about, sketched amidst, manipulated, and visually assembled—in a continuous zoomable space—in order to create conceptual and spatial contexts [36].

Collaborative Live Media Curation extends free-form web curation. CLMC integrates live streaming modalities—e.g., webcam video, screenshares, audio, and text chat (see Figure 6.1)—to support participating in shared learning experiences. Further, where prior implementations of FFWC only supported a single user at a time [36, 37], CLMC incorporates *collaborative and synchronous* collection and assemblage of media elements, which becomes a new live communication modality. By enabling the collaborative assemblage of media, we ultimately aim to support the creation of live media places to support online communities (see Section 1.1.4).

However, in this work, we specifically explore the following research questions: How do students and instructors use CLMC to support and engage in learning activities? How can we further support participation in online learning experiences? To explore these research questions, we design and develop LiveMâché [148], a technology probe [33], for collaborative live media curation. We deployed the LiveMâché probe in four situated online learning contexts to provoke and collect data about new experiences. During these situations we observed emergent strategies for sharing context and participating in learning activities using CLMC. We also develop implications through live experience patterns, which describe how spatial and computing structures support social activities.

6.1 Prior Work

To frame the present research, we introduce some prior work. First we discuss sharing visual context for conversational grounding. We then introduce the medium of free-form web curation, and its strategies for contextualization, which we extend to form collaborative live media curation.

6.1.1 Conversational Grounding: Shared Context

Prior research has investigated the role of shared visual context in collaborative work [142, 149, 150, 151]. Fussell et al. argue that developing virtual co-presence through shared visual and linguistic context is critical for establishing common ground, information that all participants in an activity are aware of [152, 142]. Conversational grounding is the iterative process by which participants exchange information to frame shared understanding [152]. Kraut et al. later showed that media providing shared visual context enables participants to more effectively complete complex tasks using deixis [149]. Deixis is the use of deictic language, i.e. language dependent on context, such as other language, gestures, or images, e.g., pointing at "that". In the present research, we show how CLMC enables participants to perform deixis to ground discussion around complex ideas through shared visual and linguistic context.

Others investigated the use of remote gesturing in collaborative work [153, 154] and instruction [143]. Fussel et al., in work investigating pointing and sketch gestures on live video to support collaborative tasks, argue that gestures facilitate grounding by enabling participants to simultaneously communicate multiple pieces of information [92]. Kirk et al. found remote gesturing benefits remote instruction and learning [143]. Citing Clark [152], McNeill [155], and Kendon [156], they argue that the performance of gesture, to contextualize language, supports the construction and communication of meaning [143]. Much prior work on shared visual context and gestures focuses on performance and the efficiency of physical collaborative tasks [142, 149, 143, 154, 150, 151]. In this work, we do not focus on physical tasks, but report on emergent use of CLMC for sharing context and performing gesture in online learning activities.

6.1.2 Free-Form Web Curation: Creating Context

Free-form web curation (FFWC) is a visual medium for collecting and assembling media, in order to support creative cognition and the emergence of new ideas [36, 37]. FFWC is inspired by *curation* in art—the conceptualization and creation of a *context*, in which works are found, collected, interpreted, and arranged—to stimulate active engagement and visual thinking [147].

Strategies of free-form web curation were articulated based on diverse artistic and scholarly practices: Collect, Assemble, Shift Perspective, Sketch, Write, and Exhibit [37]. Students made extensive use of the strategies in creative engagement with prior work [37]. FFWC was also shown to support students in visual thinking [36]. To support participation in learning activities and other CSCW, this research extends FFWC to develop a new collaborative and social medium, with synchronous support for multiple users and live streaming media.

Collect is the gathering of content elements. The diversity of collected elements promotes ideation [157, 158, 159]. Central to the collect strategy is the *found object*, a conceptual technique in which one takes an ordinary article, exhibits it with a new title, places it in a new context, and so transforms its meaning [23]. The current probe enables diverse media types to be collected from the web.

The *Assemble* strategy involves visual organization of elements to express relationships and convey meaning. In art, *assemblage*—the process and means of fastening found objects together—is used to highlight duality and tension between the original and resulting contexts of found objects [160]. In FFWC, this has been shown to promote creative cognition of relationships among collected media elements, supporting ideation [159, 161, 37].

Shift perspective involves navigating a curation space to different views. Here, this is accomplished with a zoomable user interface [162]. *Sketch*, which involves making marks depicting abstract or concrete relationships or ideas, has been shown to be a generative means for design ideation [163]. *Write* is the articulation of ideas through text; shorter writing involves labeling categories; longer writing involves exposition. *Exhibit* involves sharing, experiencing, and engaging in discourse.

6.2 LiveMâché Probe

In order to explore the use of CLMC in online learning contexts, we designed and developed LiveMâché [148] for use as a technology probe. LiveMâché is a cloud based web application implementing collaborative free-form web curation. The probe integrates typical live streaming modalities including text chat as well as streaming audio and video. Finally, LiveMâché supports

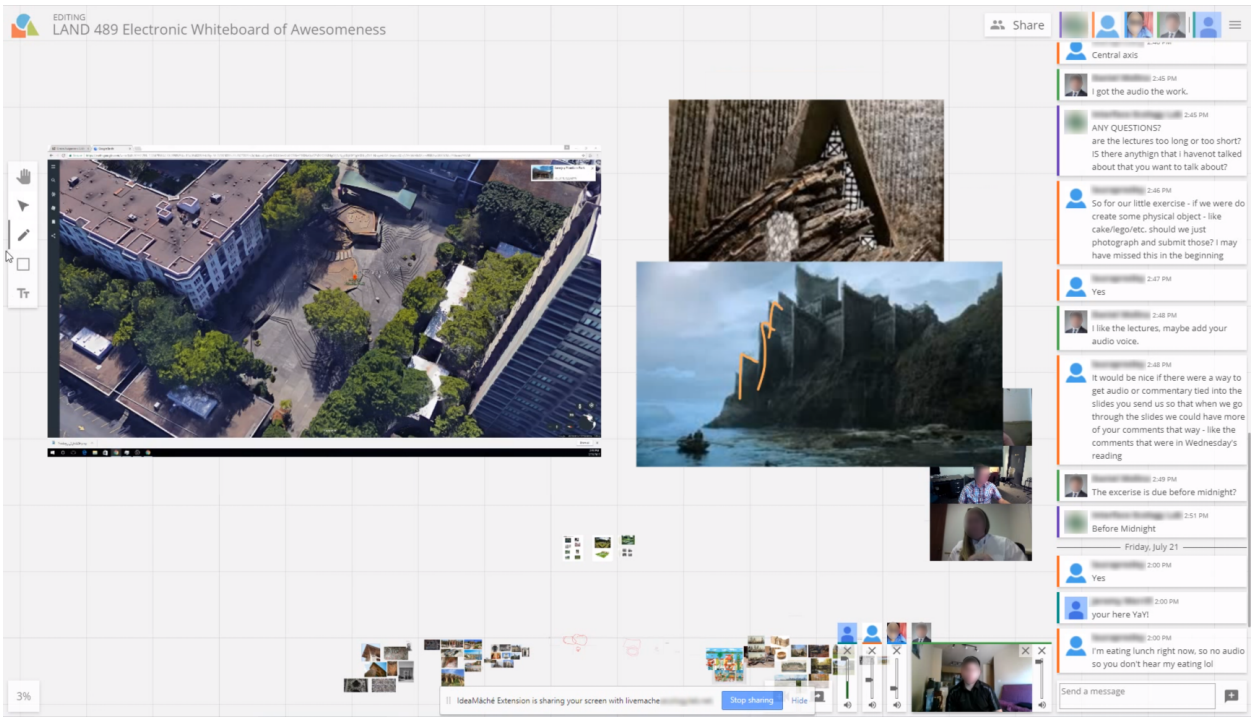

Figure 6.1: A screenshot of the LiveMâché probe. LiveMâché implements CLMC, providing a synchronized media assemblage space (center). It also integrates live modalities including text chat (right), live streaming audio and video (bottom right, and middle right), and screensharing (center left). In this observed example, C4I is discussing the landscape architecture of a park using a screenshare of Google Earth on the left. He asks his students if the park's architecture reminds them of other contexts they have seen. C4S1 responds that it reminds her of Dragonstone from HBO's popular television show Game of Thrones. She then collects two images of the fictional castle to ground her point. C4I proceeds to sketch on and discuss the castle's architecture. Reprinted from [62].

participant roles and sharing perspective. We present here the design motivations and resulting capabilities of the LiveMâché probe.

6.2.1 Collaborative Free-Form Web Curation

To enable the collaborative creation of media curations, for supporting live learning activities, the LiveMâché probe brings synchronous collaboration to the FFWC strategies: collection, assemblage, sketching, writing, shifting perspective, and exhibiting [37]. Users can collaborate both synchronously and asynchronously to collect a wide range of media from the web and their personal devices. They assemble collected elements in a shared, near-infinite zoomable canvas.

They use visual transformation, updated in real-time, to further relate and synthesize elements. Collaborative sketching and writing help users think about and communicate ideas.

6.2.1.1 Real-Time Collecting and Assembling

In order to support flexible collecting of content, the LiveMâché probe enables gathering and transforming media elements—including images, text snippets, videos (YouTube and Vimeo), Google Docs, and Google Maps—from the web. Users collect content directly from their web browser or file system by dragging and dropping it into the zoomable curation canvas (Figure 6.1). The canvas is a near-infinite zoomable space in which the user can pan and zoom their viewport using the mouse or keyboard. Each curation begins as an empty space with no predefined or suggested structure. As soon as an element is dropped onto the canvas, it immediately becomes visible to all other users. Users assemble their curation as they gather and arrange elements.

In order to support the development of ideas and construction of new meanings, LiveMâché enables expressive visual assemblage through graphical transformation of media elements, e.g., position, scale, rotation, and layer. Any element can be repositioned by clicking and dragging it to a new location. When collected, an element's initial scale is determined by the zoom level of the user's viewport. Elements can be scaled larger or smaller at any time. Scaling elements, in conjunction with the zoomable user interface, enables users to create arrangements which span multiple levels of scale. Layer transformations enable users to position elements behind or in front of others. All visual transformations are synchronized, in real-time, across all instances of a curation.

6.2.1.2 Real-Time Sketching and Writing

To support authoring and annotation of ideas, the LiveMâché probe supports collaborative sketching and writing. Users can freely sketch within a curation. These sketches can be on empty sections of the canvas or they can overlap other elements. Users can adjust the size and shape of the sketching brush and select a color from a preset palette. While a user is sketching, other users see the partial sketch, in vivo, as it is drawn. Our motivation for supporting lightweight sketching,

is to support visual thinking [164] and the expression of the images and forms in the minds' of the users [163].

Similarly, collaborative writing supports exposition, which involves labeling, explaining, expounding, and verbally illustrating. Within the curation, users are able to create, edit, or paste in text elements. Text can be created, layered, and manipulated in the same manner as as all other curation elements. By default, the initial font size of a newly created text element will automatically scale in relation with the current viewport zoom level. As a user edits a single text element, changes are continuously synchronized in real-time. While only one user can edit a text element at a time, different text elements can be edited simultaneously by different users.

6.2.2 Viewport Following

To support sharing perspective in collaborative curations' exhibition experiences, we incorporate tools for following viewports in LiveMâché. The viewport is the mechanism that controls what each user sees. In FFWC, users engage in the shift perspective strategy to situate their view of a curation. We developed *viewport following* to enable users to continuously shit perspective with another user. To follow another user, a participant simply clicks on their avatar in the upper right of the interface (see Figure 6.1). While following another user's view, the user's viewport is continuously centered on the same point as the followed viewport. A minimum zoom level, encompassing the followed user's viewport, is then used. During continuous perspective shifts, such as zoom and pan, the following user's view is updated at approximately 20Hz. In order to stop following another user's perspective, a user directly retakes control, moving their own viewport by panning or zooming. If a user tries to follow a user who is currently following a third user's viewport, they automatically start following the third user.

6.2.3 Live Media Modalities

In order to support sharing experiences and participating in learning activities, the LiveMâché probe integrates communication modalities that have become typical in live streaming: e.g., synchronous text chat, video, and audio. These modalities have been shown to support shared context,

communication, and participation in live experiences [48, 75].

6.2.3.1 Text-Chat

Text chat has been shown to serve as a light-weight, non-intrusive communication modality, supporting participation by large numbers of users [113, 48]. LiveMâché incorporates persistent text chat, overlaid on the right side of the curation space (see Figure 6.1). Messages are displayed with the sending user's avatar and a timestamp. Chat messages can be collapsed to provide a greater view into the curation space.

6.2.3.2 Live Streaming Audio and Video

In order to support real-time discussion and views of activity, LiveMâché enables adding live streaming audio, webcam video, and screenshares into shared curations. Audio and webcam video streams are added to a curation using a modal dialog, allowing the participant to select and preview the desired video and audio source (not shown). Once added, webcam video thumbnails and audio stream controls are shown in an overlaid, fixed dock in the lower right hand (Figure 6.1).

In the dock, audio streams are represented as small meters. These meters include a slider knob for adjusting each respective audio stream's volume. Audio volumes are synchronized for each client, enabling participants to control the shared volume mix of the curation. Each meter also displays a dynamic green bar representing the audio activity for its respective audio stream. Video streams in the dock are rendered as small video thumbnails alongside each participant's audio meter. Each participant's streams in the dock are displayed together along with their avatar and name on hover (Figure 6.1).

In early testing, we found it is often is more appropriate for webcam video and audio to be situated independently of a user's shifting perspective. A participant's facial expression and speech is often important for the whole activity context, not at a location in the curation. For this reason, webcam video and audio tools are initially placed in the dock. However, if a participant wants to situate a webcam view within the media assemblage of the curation, LiveMâché supports simply dragging live video streams directly into the shared curation space. The video is then directly

embedded in the curation and can be transformed like other media elements. Video elements can be moved back to the dock using an on hover button.

Participants can add live screenshare streams into the curation (Figure 6.1). To do so, they must install a browser extension, to meet security requirements. In early deployments, we found that screenshare streams are most likely to be used for sharing views of activity. Thus, LiveMâché automatically adds screenshares into the composition space instead of the dock, where they can be readily assembled with other media elements.

To capture and broadcast participant audio and video streams, LiveMâché uses the open source Jitsi Videobridge project [165]. Jitsi Videobridge enables web clients to send and receive media streams using WebRTC, an emerging web standard for real-time communication [166]. By using Jitsi Videobridge and WebRTC, LiveMâché functions as a collaborative web-based live media curation space, the first we are aware of.

Prior work found that combining multiple video streams—particularly video streams of people and views of activity—effectively supports sharing, participating, and collaborating in live experience [58, 63, 48, 75]. We modified Jitsi Videobridge to support multiple video streams from a single client. Low latency in communication modalities is critical for efficient communication and grounding in collaborative tasks [167]. LiveMâché is able to transmit video and audio streams with sub-second latency. LiveMâché also utilizes Simulcast, a WebRTC feature for on the fly adjustment of video resolution for balancing quality and bitrate [168].

6.2.4 Permissions and Roles

In live streaming practice, in order to organize participatory experiences, streamers often make decisions about when and how their viewers can engage through modalities, such as gameplay, text chat, or voice [48]. Thus, we wanted to support instructors and students in making decisions about how other participants can engage and applying structure to their curations and activities. To this end, LiveMâché implements a basic permissions and participant roles system, drawing from observed practice and capabilities in other collaborative tools.

Similar to Google Docs, curation authors are able to make their curations public or private.

Public curations can be viewed by anyone who has the link. Meanwhile, private curations are only shared with users who are explicitly assigned a role.

Authors can assign users one of three predefined roles: *viewer*, *commentator*, and *editor*. We model these on roles observed in live streaming practice, on platforms such as Twitch [48]. Viewers can see everything that happens in a curation space, but are only able to engage with other participants through the text chat modality. This role models that of a live stream viewer. Commentators can additionally add video and audio streams to the curation, enabling them to comment on activity. This is like how a video game commentator, or remote player, participates in a stream on Twitch. Third, beyond the commentator live modalities, editors can engage in collaborative FFWC. Editors may also assign roles to other participants and control or remove others' media streams. The editor role models that of 'streamer' in live streaming practice. In addition to assigning roles to specific users, editors may choose a default role for all other participants in a public curation. We note that LiveMâché interface elements dynamically change, or are removed, as a participant's role changes.

6.3 Study Design

In order to observe emergent use of CLMC, we deployed LiveMâché as a technology probe. Technology probes are functional technologies that are deployed in situated real-world contexts [33]. They are intended to field test, provoke, and collect data about new experiences.

We deployed LiveMâché in four different situated online learning contexts. These include a local human-centered computing graduate seminar, a MOOC on edX, an informal perspective drawing tutorial, and an online undergraduate landscape architecture history course. The activities conducted in each of these situations was different. Instructors worked with us, in advance, to conceptualize and setup learning activities. We video-recorded participant curations during each situation.

We also conducted semi-structured post-interviews with students and instructors regarding their experience participating in probed learning activities. In total, we interviewed ten students and two instructors. Interviews lasted 20-50 minutes. Interviewees were compensated with a 15 USD gift

card.

Our analysis of the interview and learning activity recordings follows the critical incident approach, in which analysis is focused on significant or pivotal activity [169, 170]. Two of the authors identified critical incidents from observation notes taken during the learning activities. Critical incidents included points where emergent behavior relevant to our research questions or significant breakdowns occurred. We targeted questions about these incidents during interviews. Focusing on these incidents, we transcribed and categorized interview and activity data using open coding to form a grounded set of emergent themes. Initial themes included multimodal interactions, deictic interactions, avoiding interruptions through text chat, annotating other participant's elements, social cues, following other users, is anybody watching me, awareness of other participants, collaborative audio adjustment, and organizing activity. We discuss some of these as findings.

In the following subsections, we describe each probed situation including its participants, content, and use of LiveMâché. We refer to each of the situations using the identifiers C1–C4. We refer to participants by their situation's identifier followed by either an I or S<N> to denote the instructor or a student respectively, where N is a number identifying specific students. For example, C1I is the instructor in the first situation, while C1S3 denotes that situation's third student.

6.3.1 C1: Human-Centered Computing Graduate Seminar

We deployed LiveMâché in a graduate seminar course offered at a local university. This first deployment was intended to be formative in nature. The seminar focused on the theory and design of human centered media experiences. It required that students work on research projects. There were a total of 12 students, involved in 3 group projects of 2-3 students, while 4 students worked as individuals. Throughout the course, students presented and discussed their work in informal presentations to the class. Presentations normally occurred in a classroom.

In one class session, students were asked to present and discuss their projects using LiveMâché. Participants used a single shared classroom presentation curation, with designated spaces for each project group. All participants were assigned the role of editor. Students prepared their presentations, in the curation, by collecting, authoring, and composing media including images, YouTube

videos, GIFs, text, and sketches.

The students and instructor added live webcam, screenshare, and audio streams to the curation, in order to present and otherwise participate in the live curation as seminar classroom. Project group members presented together, fluidly alternating who spoke and demonstrated. Presenting students referenced their prepared media. During and after each presentation, students fielded questions and comments from the instructor and other students. We interviewed the students C1S1–C1S5.

6.3.2 C2: Mobile Application Experiences MOOC

For the second situation, we deployed LiveMâché in "Mobile Application Experiences" a popular edX course. The online course addresses the design, usability, implementation, and evaluation of novel mobile applications. We targeted the course in order to explore how to support engaging visual design education tasks in software development education.

The instructor asked students to volunteer to use LiveMâché to create a digital poster explaining their final project, a mobile application prototype. The digital posters were prepared in advance. Students were asked to present their projects to the instructor and other students during one of two poster sessions. Sessions were scheduled 12 hours apart to accommodate international students' varying time zones. Six students signed up to participate. However, only 3 students were present during the scheduled times. These 3 attended both sessions.

One hour prior to each session, we hosted a green room curation, in which all of the students were assigned the editor role. Students were encouraged to join and ask us questions about LiveMâché as well as test their video, audio, and screenshare streaming settings. In the green room, we posted the list of the participating students, with links to their poster curations.

At the start of each session, C2I and students met in the green room. C2I would then chose one of the students to present their poster, following the link to the presenter's curation. In poster curations, the presenter and C2I were editors, while other students were viewers. The student typically added audio and a screenshare of their mobile application running in an emulator. The instructor added a webcam and audio stream of himself. We note that, in one of the presentations,

C2I wasn't able to add his audio stream, and used chat instead. Presenting students explained their application, referencing their poster and screenshare. Following their explanation, C2I and the student engaged in a short discussion about the project. Other students gave feedback via text chat. This process was repeated for each student. We interviewed C2S1 and C2S2.

6.3.3 C3: Perspective Drawing Tutorial

For the third situation, we deployed the LiveMâché probe to support an informal drawing tutorial. The tutorial was presented by a local student. Participants were recruited using the researchers' and the instructor's social media networks. The tutorial was attended by 4 students collocated with the instructor and 3 remote students.

The tutorial took place in a lab space instrumented with three webcams oriented to provide close-up shots of the instructor's and students' drawings, a webcam providing a wide shot of the room, and a large display showing the instructor's view of the tutorial curation. Local participants sat around a large table, where they could easily watch the instructor work through the tutorial curation on the large display. The room was also equipped with a condenser microphone to pick up and broadcast the instructor's and local participants' discussion.

The condenser microphone audio stream and webcam views of the physical tutorial space were added into the shared live curation. Remote participants were assigned the role of commentator, so they were able to interact with the local participants by adding their own video and audio streams to the curation. We observe that 2 of the 3 remote participants chose to engage using a live audio stream.

C3I began by discussing basic concepts of perspective drawing. To illustrate his points, he sketched over (using the LiveMâché sketching capability) photographs and sketches he had collected prior to the tutorial (Figure 6.2). After going over these concepts, he switched to demonstrating and narrating the discussed techniques, by drawing with a pen on a sheet of paper. This was captured and broadcast by one of the webcam views in the live curation. During this time, C3I encouraged both local and remote participants to follow his view and attempt to sketch their own perspective drawings. Additional webcam views in the room were added to the curation to capture

and broadcast the local participants' efforts. Next, C3I viewed and discussed the local participants' drawings using his desk webcam. Later in the tutorial, C3I made students editors and encouraged them to share pictures or live videos of their drawings, but none did. We interviewed C3I, C3S1, and C3S2.

6.3.4 C4: Landscape Architecture History

For the final situation, we looked at how LiveMâché would be used over an extended period. We deployed the probe in a SPOC on the history of landscape architecture. The course was taught over 5 weeks during a summer semester. It had 4 enrolled students. C4I used LiveMâché to conduct 4 weekly live chats to supplement the course's other content. Each week, C4I would send out two sets of slides, which constituted the main content of the course. Then, during the live chats, C4I and the students discussed important content covered in these slides.

Prior to each live chat, the instructor would collect media (usually images of landscapes) illustrating the concepts he planned to cover. In the final two weeks, the instructor also used screenshares of Google Earth, through which he explored examples of landscape architecture from around the world. He also incorporated slides into the curation, using screensharing. The instructor frequently sketched over assembled media elements as he discussed them. During each live chat, the instructor assigned students the role of commentator. He required that they add audio streams and, optionally, webcam views of themselves to the curation. This enabled the students to easily ask questions and engage in the live chat. In the second week, C4I had students present assignments. To support this, he added student submitted images of their assignments to the curation, which they then referenced during presentations. In the third week, C4I also made his students editors in the curation for a short time, so they could collect and assemble media to discuss during class. We interviewed C4I and C4S2.

6.4 Findings and Discussion

We present and discuss findings from deploying the LiveMâché probe in these 4 situated online learning contexts. The findings and discussion are presented together, in order to ground our

discussion with description of observed phenomena. We first report on emergent strategies we observed participants using to share context and ground their collaborative learning activities. We then discuss how the synchronous capabilities of CLMC function as a new participatory modality. Finally, we identify patterns of live experience that emerged during the probed situations and discuss resulting implications.

6.4.1 Collaborative Live Media Curation Strategies

In each situation, we observed participants using CLMC to establish shared context supporting their learning activities. Participants engaged in deixis, using language to reference collected content, grounding discussion in the shared context defined by their curation. Kerne et al. articulated *strategies* of free-form web curation, each of which addresses methods and techniques that artists, curators, and scholars employ—and which in many cases have been investigated by creative cognition researchers—in creative acts [37]. We extend their strategies to collaborative live media curation, by identifying how participants share context, ground conversation, and perform deixis.

6.4.1.1 Creating Shared Curation Space in Advance

In each probed situation, participants worked to create curation spaces before the actual live engagement. Participants, students in C1 and C2 and instructors in C3 and C4, collected media, wrote text, sketched, and assembled curations prior to each activity. For example, prior to his tutorial, C3I collected images exemplifying perspective (Figure 6.2). He subsequently used the context of these collected media elements to ground his early instruction, by referencing and sketching over them.

Participants found it valuable to asynchronously assemble curation spaces in advance, then engage in synchronous curation, on the fly, during the learning activity. By collecting and assembling content, they established context for upcoming activity, where they subsequently created shared meaning.

Figure 6.2: Photographs and drawings exemplifying perspective collected by C3I prior to presenting his tutorial. During the tutorial, he sketched over these images to illustrate perspective drawing techniques. Reprinted from [62].

6.4.1.2 Sketch: Illustration and Gesture

Participants in C1, C3, and C4 used sketching over other media elements in order to ground their descriptions of a particular concept. Sketching was used to directly articulate ideas related to other curation elements. We observed participants not only using sketch to illustrate concepts, but further, as deictic gesture to call attention to particular features of other elements as they discussed them. We give examples of both uses here.

C3I started his perspective drawing tutorial by explaining concepts of vanishing points and lines. In order to do this, he collected exemplary images, including photographs and drawings, before the tutorial. During the tutorial, he then sketched over these images, to illustrate, by sketching dots at the vanishing points and lines along the vanishing lines of the image (Figure 6.2). Using this approach, C3I was able to ground his discussion of vanishing points and lines by illustrating the concepts using his previously collected media. C3I left these sketches in place, throughout the tutorial, as a reference.

C4I also extensively used sketching to facilitate discussion of landscape architecture examples. He would often sketch over elements depicting landscape architecture sites, e.g., photographs or screenshare streams of Google Earth. While he used sketching to illustrate concepts, he also used sketch gesture to focus students' attention on particular design features of the sites. He described the architecture of a particular park, while sketching over a Google Earth screenshare (Figure 6.3):

> C41 You can see the building right over here [draws a quick circle in orange around the building behind some trees]. Right through those trees there. Now Kiley has given us this meandering path. [draws curvy line along a bricked path through the park]. Because this part is separated by all of these trees... [scribbles green lines over trees] So all of these trees are screening the building. So you don't have that neoclassical influence on your aesthetic experience anymore. Now you are in a different type of park. Now you are actually in part of, you are in a different sculpture garden, because look at that [circles a sculpture in red]! That is a very modern art piece...

In this case, C4I uses sketch as deictic gesture. To indicate the trees in "all of these trees", he sketches over the trees in the screenshare. C4I is not directly illustrating a concept. He is using sketch to reference and ground his vocal explanation of the site. After making these quick sketches, C4I usually deleted them, since they lacked continued illustrative purpose.

6.4.1.3 Real-time Element Transformations

One of the primary strategies participants used to engaged in deixis was the dynamic transformation of media elements. Since element transformations are synchronized across participants' views of a shared curation, participants were able to express complex ideas through language contextualized in gesture performed through media transformations.

In one salient example, C4I was discussing the work of Antoni Gaudí, a well known Catalan architect. He described Gaudí's practice of modelling architecture, using upside-down force models, with hanging weights and string. To do this, he started by collecting a picture of one of Gaudí's hanging models from Google Images. After briefly describing the construction of the model, C4I

Figure 6.3: C4I discusses the design of a park. He sketches over a Google Earth screenshare as deictic gesture to ground his description. Reprinted from [62].

then used the rotate transform tool to flip the image of the model upside down (see Figure 6.4), while explaining:

> What he did actually though was, he designed a building. So now you can see, these strings... He was making a physical model of showing how the forces of gravity were going to pull on these archways.

By rotating the image to invert it, C4I was able to ground his explanation using the image of the model. He used the act of rotating it as gesture to explain its inverted nature. He then used the inverted image as a shared visual context for himself and his students, to ground his explanation of the model's purpose. He went on to sketch over the image, highlighting the arches and weights composing the hanging model.

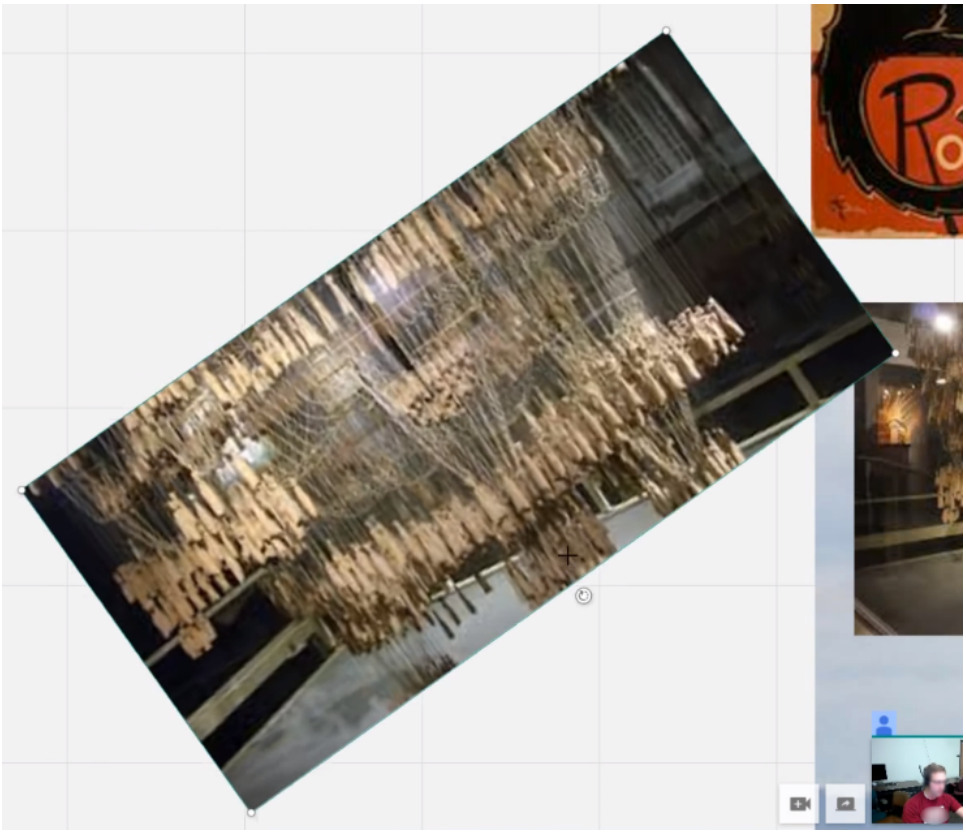

Figure 6.4: C4I explains Gaudí's use of hanging models. He performs a rotation transformation on an image of a model to ground his explanation. Reprinted from [62].

6.4.1.4 Sharing Perspective

The viewport following capability was used by participants, in every situation, to ground conversation through shared visual context. Viewport following was used by participants watching a presentation made by the instructor or peers. While other participants followed his viewport, the speaker would discuss a concept, while shifting perspective, to focus on a particular set of media elements in the curation. In turn, other participants would see the speaker's visual context changing, grounding his points with media curated into the participant's viewport.

The FFWC strategy of shift perspective is a means through which an individual reorients their view in a curation [37]. A compelling aspect of the shared viewport capability is that when a participant shifts their perspective, others literally follow, in the space, and so dynamically share their

changing visual context. Participants in C1 reported that while they made extensive use of viewport sharing, they hardly thought about how their audience was viewing the curation. However, we did find that sometimes more purposeful consideration motivated perspective shifts. When asked about how he thought about shifting perspective during his live chats, C4I reported:

> I didn't want it to fill the screen. I wanted you to be able to see the things on the periphery, so that you would know that it was connected to other things. When I laid things out, I wanted them all the same size, but I wanted them to be organized in a sort of structure that talked about [how] these things are related. So when I zoomed in, I wouldn't try to fill the whole screen with one thing. I liked a little bit of white space around it, and just a little touch of other things. So there is this idea, this thing doesn't exist in a vacuum. It is actually related to other things.

Here, C4I explains how he deliberately shifted his perspective to ensure that media elements remained contextualized within the broader curation for his audience.

6.4.1.5 Assembling Webcam and Screenshare Streams

Live streaming video was used extensively in all the situations to contextualize learning activities. Participants primarily accomplished this by adding screenshares of applications they were using or demonstrating. Webcam streams were also used to share views into activity. Since LiveMâché supports directly embedding live video streams into the curation canvas, streams can be assembled, sketched on, and transformed, like any other element, to construct context. We briefly describe some instances of participants assembling live streaming video.

During the student poster presentations in C2, students were asked to demonstrate their final project mobile applications. In addition to discussing their prepared posters, students would assemble a screenshare stream of their application running in an development emulator, in the curation, next to their poster. This enabled students to ground their discussion by connecting live views of their application with prepared poster materials.

C3I used a live webcam stream to show himself demonstrating perspective drawing techniques.

The stream provided an overhead view onto his desk, where he was drawing, using pen and paper. C3I used the stream to ground his explanation of perspective drawing techniques, for local and remote participants. The stream was assembled into the curation, with other video streams of the room, providing multiple views of the activity. These streams were augmented by images, which C3I sketched over, to illustrate perspective drawing concepts.

In the C2 and C3 examples, participants contextualized activities by situating live stream activities by assembling other media. They engaged with the live media using the above strategies for sharing context. For example, C4I sketched over screenshares of Google Earth, which he used to explore landscape architecture sites.

6.4.2 Collaborative Curation: A Participatory Modality

CLMC integrates prior live streaming modalities such as video, audio, and text chat, each of which affords participating in live experiences. However, prior work has shown that new modalities can support new forms of participation [52, 57, 74, 75]. Beyond existing modalities, CLMC enables participants to engage by collaborating in the assemblage of shared media curations. Participants with the editor role can collect media, assemble it, share their perspective, sketch, and write in the shared curation. Each of these synchronous capabilities can serve as a new modality for participation.

For example, in C1, each team assembled a curation for the discussion of their project. During class, each team described their work, referencing their previously assembled media. Students who were watching the presentations participated by authoring text and sketching to annotate the presenters' collected media to give feedback, pose questions, and make suggestions.

During the third week of C4, a student collected images to contribute to and participate in live chat discussion. While discussing the architecture in a particular park, C4I asked the students if it reminded them of anything else they had seen. C4S1 responded that it reminded her of architecture she had seen in the popular HBO television show, Game of Thrones. At this point, C4I made all of the students editors of the curation and suggested that C4S1 try to find some images of the building she was thinking of. C4S1 went and found two images of the fictional castle Dragonstone, and

added them to the curation (see Figure 6.1). C4I commented on Dragonstone's asymmetry and sketched over the collected images to highlight the castle's lines, noting their repetitive style.

In both of these cases, we see students engaging in learning activities by collecting, authoring, and assembling media using CLMC. Thus, collaborative curation served as a new modality for participating in social learning activities.

6.4.3 Live Experience Patterns: Structure Supporting Activity

During the probed situations, we observed the emergence of recurring structures of live experience and social activities. We refer to these here as patterns of live experience, drawing on Alexander's notion of patterns, which are recurring forms of spatial organization that support particular types of experiences and events [171]. Where Alexander referred to spatial patterns in architecture, the patterns we discuss here describe organization of modalities and computing resources to support live social activities. We note that these patterns are not limited to CLMC. They may be found in other live social media forms, such as Twitch, Periscope, Facebook Live, Skype, Google Hangouts, etc. Live experience patterns we identify include include small team, broadcast, and touring. We present examples of how these patterns were manifested by users, and abstract from examples, focusing on how the affordances of CLMC contributed to their structure. We also address how the patterns are invoked in other live media forms.

In the *small team* pattern, we typically observe a curation shared with two or more participants given full editing access. Workflows and roles are then worked out through ad-hoc articulation between participants. An example of the small team pattern arises in C1, in which everyone had equal access to the curation. Who presented when, who was speaking, and where participants prepared their presentation was established through informal social articulation. The small team pattern is typified by prior tools, such as Google Hangouts and Skype.

The *broadcast* pattern is more asymmetric, with one or more core participants broadcasting live media and editing the curation. All others participate using limited, peripheral modalities, like text chat. We specifically observed this pattern of use in C2, where the poster presenter and instructor had a live video / audio discussion, while other students observed the presentation and

discussed through text chat. In CLMC, the broadcast pattern can be organized by assigning a few participants high impact roles like editor or commentator, assigning all others the viewer role. The broadcast pattern is typical of live streaming forms such as Twitch or Periscope.

Finally, in the *touring* pattern, participants move together between social activity contexts. During the student presentations in C2, we observed touring, where participants moved between and interacted across several different curations. In our study, touring was supported by providing links to each poster curation in the green room, with the instructor directing participants to move between them. We note that the touring pattern can also be observed in other live streaming forms. For example, Twitch streamers can "host" other streamers, effectively shifting their audience to another stream. Future research that explores how to support maintaining social context while groups tour live media contexts would be beneficial.

In prior live media forms and in CLMC, live experience patterns are collaboratively established through explicit system enforced roles, ad hoc articulation of social roles, and the assemblage of modalities. This curation of roles and modalities is performed by organizers, i.e. streamers or instructors, to control the media's content, how it is perceived, and how others may participate. A poorly assembled media curation may result in limited participatory opportunities or cognitive overload. CLMC enables curators to freely assemble modalities and roles to create media contexts that supports the needs and requirements of their situated social activity. In the following, we discuss issues and approaches that we hypothesize may support structuring live experience through curation.

6.4.3.1 Structuring Live Experiences Through Roles

The LiveMâché roles system provides a flexible mechanism for structuring how curations and their respective activities are viewed, edited, and participated through. These roles specify what modalities are available for participants to use. Existing live forms like Google Hangouts (small team) or Twitch (broadcast) implement static media structures and roles. In contrast, CLMCs can be restructured by moving participants dynamically between roles. This enables organizers to fluidly transition between patterns like small team and broadcast, or to organize experiences

somewhere in between.

For instance, during most of C4 a broadcast pattern was assumed. Students were able to commentate, but C4I was the only participant able to actively compose media in the curation space. However, at some points C4I would change the students' roles to editor, shifting the experience to more of a small team pattern. LiveMâché only currently provides 3 distinct roles. Future work could explore a more diverse, nuanced set of roles that could lead to new patterns of live experience.

6.4.3.2 Live Experience Pattern Templates

While the roles provided by LiveMâché support structuring live experiences, some participants reported difficulty in thinking about how to assign roles. As C1S5 noted,

> The whole experience could get out of hand rather quickly, because it [is] such a creative system. In which, it is so open-ended, and there are is not lot of structure. [...] My thinking is that at a high level it would benefit from a little more structure in some situations. Like possibly, different templates with varying degrees of structure.

Assigning roles to support a particular pattern of experience requires significant forethought and collaboration from participants. A potential solution we plan to explore is *live experience pattern templates*, as mentioned by C1S5. For example, when a participant creates a curation, they may be given the option to use a broadcast template. This template would have preconfigured role assignments, so the creator could edit and broadcast video and audio, with a default role of viewer for other participants. Templates would support thinking about roles and scaffold the work needed to organize activities.

6.4.3.3 Territories

Another approach that emerged for structuring live experiences was the use of territories within a curation associated with a specific participant or group. In C1, each group was given an area in which to prepare media for their presentations. These territories were implicitly agreed upon and denoted via a grid of text elements of participants' names. Given that the territories were not

computationally enforced by LiveMâché, we did observe instances of participants manipulating others' elements or revealing intentionally hidden content in others' territories. While these interactions were mostly beneficial and sometimes playful, it is easy to imagine situations where these interactions would be less acceptable.

This suggests that enforced territories in a curation might help structure shared activities. Territories would support spatially defining how curation space is assembled and seen. This could help participants articulate their roles and define social context. We note that the use of territories for coordination in tabletop systems has been investigated [172, 173]. Future work investigating the use of territories in zoomable collaboration spaces like CLMC, may lead to unique considerations. For instance, a territory defined within a infinite zoomable space also provides infinite, ample room for participation.

6.5 Conclusion

Collaborative live media curation is a new medium for live CSCW. Prior live streaming forms do not afford collaborative, free-form assemblage of live modalities. By extending free-from web curation with synchronous collaboration and live media, CLMC enables a new contextualization of live experience. By deploying the LiveMâché CLMC probe in four online learning situations, we provoked new participatory online learning experiences.

We observed how participants invoke new collaborative live media curation strategies for sharing context, grounding collaboration, and constructing meaning through the assemblage of media and performance of deictic gestures. Like others, we found that shared context is based on common understanding of framing [174] and social construction of mutual understanding [175]. The strategies—creating shared curation space in advance, sketching to illustrate and gesture, real-time element transformations, sharing perspective, assembling web cam and screenshare streams—contribute new, concrete means for promoting collaborative meaning making through shared visual and social context. Collaborative free-form web curation afforded new modalities for participation. Prior forms limit most participants to limited modalities, such as text chat. CLMC's open-ended integration of media and modalities affords new opportunities for any participant to

engage in the collection, broadcasting, and assemblage of media.

We articulated patterns of online live experience. Prior live media platforms typically support a single activity pattern. For example, Google Hangouts supports the small team pattern, while Twitch supports broadcast. CLMC is more flexible, enabling participants to assign roles and assemble media to form small-team, broadcast, and touring patterns of live experience. Participants can shift between patterns, using roles, to support dynamic social contexts. Future work has the potential to provide value by exploring how new strategies for assembling and structuring media will support new forms of participation and shared context in situated live experiences.

Finally, we note that a core aim of this work is to support the creation of online live media places to support online communities. However, the present study is largely formative in nature. Future study of CLMC over an extended period has the potential to examine the establishment of placeness through media assemblage and emergent community practices.

7. CONCLUSIONS AND FUTURE WORK

In this chapter, we review some of the findings and implications of this dissertation, as a whole. We discuss how live media is being used to support online communities and how combining modalities supports new forms of peripheral and high-impact participation. We then sketch future directions for live media research.

7.1 Combining Hot and Cool Modalities for Peripheral and High-Impact Participation

We find that McLuhan's concept of hot and cool media is a useful analytic framework for understanding and discussing the participatory properties of media. The low fidelity of cool modalities enables low-impact peripheral participation at larger scale. Hotter modalities, with their saturating fidelity, support higher-impact participation at limited scale. Combining modalities across this spectrum enables participants to make choices about how they want to participate. Newcomers and less involved community members may choose to lurk or participate through cooler, more peripheral modalities. Regulars and more involved members have the option to participate through hotter, more impactful modalities.

As live streaming combines hot and cool modalities to create a new participatory form of live media (Chapter 3), we create new forms through new combinations of live modalities. Rivulet combines multiple live video streams with new sets of participatory media including global text chat, hearts, and PTT audio (Chapter 5). Collaborative live media curation incorporates live video, audio, and text chat with real-time collaborative web media curation (Chapter 6).

These new forms, through novel combinations of live modalities, support new ways of participating in shared live experience. Viewers on Rivulet participated by sending PTT messages. This served as a high impact avenue for participation. We discovered that participants who were already intensely engaged in the live experience used this new modality to participate, with a higher level of impact. In our investigation of the CLMC probe, we observed students and instructors working collaboratively to create shared visual contexts to ground learning activities. This functions as a

new participatory form, enabling participants to work collaboratively on curation of a shared media space.

As we observed in the context of Live MOOCs, incorporating a spectrum of hot and cool modalities creates more opportunities for participation. We observed similar phenomena in Twitch communities, where regulars are core community members. As regulars stick around and participate through peripheral modalities, they start to become higher impact community members. At some point, they may trusted with moderator privileges, or asked to participate in a multiplayer game play sessions with the streamer. Having a spectrum of participatory modalities from cool to hot supports the transition from newcomer to regular by providing a clear path for increasingly more impactful participation and privileges.

While we have examined many live modalities in the present work, there is still potential for the invention of many new participatory live modalities. New forms that incorporate novel cool modalities will provide new avenues for participation in live experience.

7.2 Building Online Communities With Live Media

In Chapters 3 and 4, we investigate how live media is being used to build communities and foster member participation. On Twitch, hot live streaming video is used to share rich game play experiences, while cooler modalities, such as text chat, enable viewers to take part in the experience. This combination of modalities led to the emergence of communities around shared online play experiences.

Similarly, in the case of Live MOOCs, we see that instructors are working to encourage student participation in their courses through live media. We observed how instructors engage students in real-time learning activities such as poetry close readings or pair programming. Live media activities also help extend the engagement of students, connecting them with course communities as well as broader communities of practice.

Across cases, we observe that live experiences form a core part of community identity. Live activities, as experienced through hot modalities, serve as a primary means for developing shared histories and emotional connections. Further, cool live media affords the opportunity for commu-

nity members to have impact through participation. As noted by McMillan and Chavis, member impact and emotional connection through shared histories and mutual identification are critical aspects of a shared sense of community [18].

Our analytic framework of hot and cool modalities for peripheral and high impact helps explain how live streaming is shifting the paradigm of online experience. Doing so creates new forms of online community, which are grounded in shared experience. As we discovered in Chapter 5, incorporating multiple streams and additional participatory modalities bridges social contexts and brings together broader communities. Further, we expect that the current contexts in which live media communities are forming are just the beginning. We briefly discuss some emerging contexts we are interested in investigating and supporting in a later section (Section 7.3.1).

7.3 Future Directions

We conclude by discussing future directions for investigating live media for participation. We briefly discuss potential new situated social contexts in which to investigate live media phenomena. Next, we discuss how we may further realize collaborative live media creation and how to support new live media experience patterns and roles. We then examine how, in future work, we may work towards supporting the establishment of online community places using live media. We then briefly discuss issues surrounding harassment and abuse through live media in present live media contexts. Finally, we discuss digital games as live media, how they sparked the emergence of current live streaming practice, and how they may continue to drive the evolution of new live experiences.

7.3.1 Investigating Live Media in New Situated Social Contexts

One avenue for future research is to investigate the use of live media in new situated contexts. In Chapters 3 and 4, we explore how live streaming media is used in the context of participatory communities on Twitch and in MOOCs (Chapters 3 and 4). From this work, we derive new understandings about how live media is being used to engage participants, how media is being combined to support community activities, and how new practices are developed to meet the goals of participants. Each situated context presents unique needs and requirements. Investigating the resulting

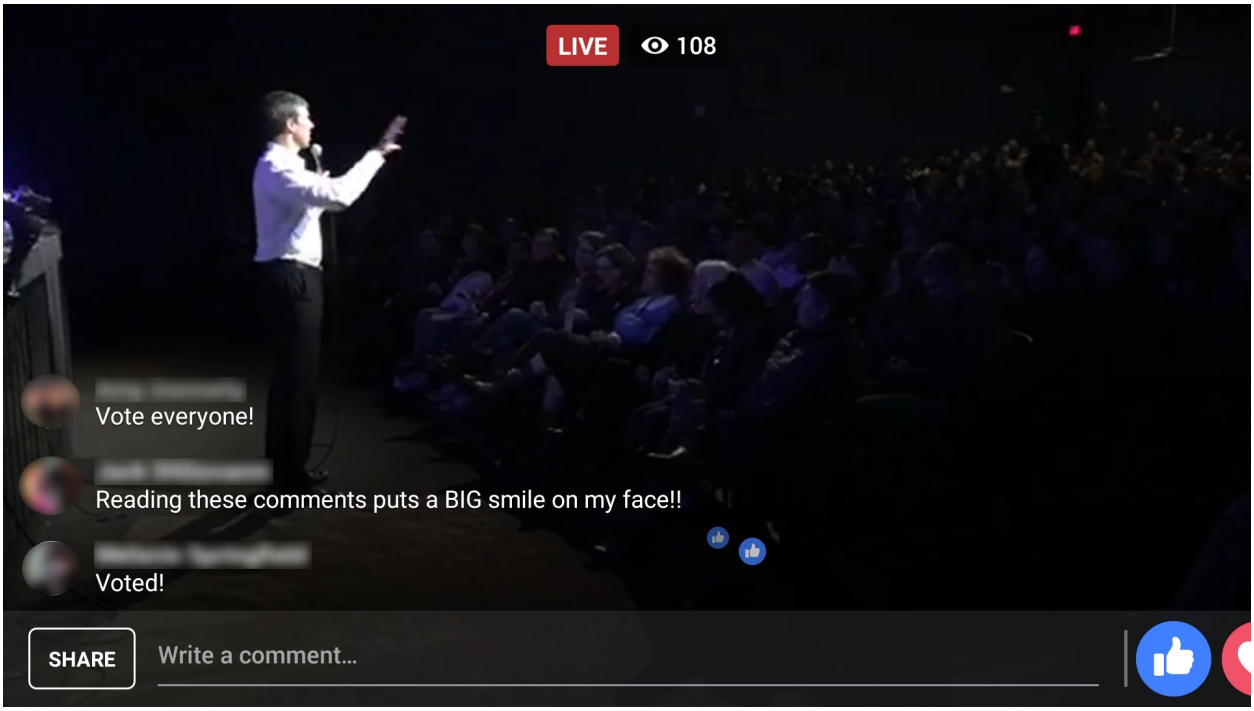

Figure 7.1: Congressman Beto O'Rourke streams on Facebook Live as he conducts town hall meetings during his campaign for U.S. Senate.

live media phenomena that emerge helps build a deeper understanding of the affordances of live media. However, there are still many unexplored and emerging social contexts in which live media is being used.

Live media is becoming an increasingly important avenue for people to engage in politics. In 2008, Twitter became a new channel for political engagement around the United States presidential election [176]. Additionally, online news organizations and political commentators have recently started turning to live streaming as a new platform for reporting on under-reported news and ideas across the political landscape [177]. Politicians are live streaming to build and connect with their grassroots audience [3]. For example, Congressman Beto O'Rourke frequently live streams on Facebook Live, as he campaigns for United States Senate, to reach a wide audience of potential supporters (see Figure 7.1) [2]. Further, activists are using mobile live streaming to broadcast their activities to a global audience [5, 4]. There is limited work investigating the resulting practices and social impact of these new political live media phenomena.

Figure 7.2: A mock up of how telepresence robots might be used to support political activist events. Reprinted from [6].

We are particularly interested in investigating how live media can engage people in political movements. How can we incorporate new media forms to empower people's voices and support effective conversations about policy? How can we support everyday people in running for office and building a grassroots movement through live media?

Beyond politics, live streaming is finding it's way into other everyday activities. Churches are live streaming their sermons to their parishioners [178]. People are streaming themselves while they cook [179] or prank people [180]. Further, live media is also becoming an important source for crisis informatics [181, 182]

Each of these situated social contexts presents an opportunity to learn about live media and practice. New live media forms or combinations of modalities may emerge from the unique requirements of any particular context. Alternatively, researchers may probe new contexts with new modalities or forms. For example, we may examine how the use of remote agency devices impacts political activism (Figure 7.2) [6], or how high-impact participation modalities and video affording

choice impact live religious community activities. Through probes such as these we may develop a deeper understanding of how to support live community activities.

7.3.2 Realizing Collaborative Live Media Creation

We note that there is a significant body of research investigating collaborative and even participatory live media production practices and technologies [55, 138, 50, 81, 139, 140]. Indeed, in professional live production practice, collaboration is critical [42]. However, we see that most real-world amateur live media creation, especially live streaming, remains a centralized if not purely individual activity. This is in part due to the centralized nature of networking technologies that enable most internet based live media production and transmission.

As we see in the reviewed work and in our later chapters, the collaborative creation and management of live media presents a significant opportunity for distributed community participation. Further, we hypothesize that collaborative media assemblage will support communities in creating media spaces and places that reflect their values and support their activities. Enabling collaborative creation of live media was indeed one of our core goals in the design of CLMC. However, we expect there is more to be investigated than what our studies have so far addressed. We imagine that a longer term, summative evaluation would elicit new kinds of activities and new participant roles.

Additionally, a lack of in the wild adoption of amateur collaborative live media creation practice suggests a need for more accessible and better designed tools. Producing live streams on Twitch remains a largely individual endeavor, with little to no support from other community members in the stream production process. In Chapter 4, we were able to see how a small team of instructors, TAs, and technical crew members were able to work together to create a complex participatory live experience for their course community. Even then, the team needed professional tools and significant expertise to pull off the experience. Additionally, this type of live learning experience remains the exception, not the norm. We envision live media environments that help people readily create these kinds of experiences to support emerging online participatory communities.

7.3.3 Blending Asynchronous and Synchronous Media Experiences

As we observed during our investigation of media practices in Live MOOCs (Chapter 4), asynchronous and synchronous media can play symbiotic roles. Indeed, if we consider a broader media ecosystem, people engage regularly through both live as well as synchronous media forms. As Hrastinski found, synchronous media can foster social engagement and support, while asynchronous forms support reflection and discussion [104]. Future work may strive to further understand the relationships and roles of these different kinds of forms in supporting online participation.

Alternatively, we may explore how to mimic true live shared experiences through asynchronous forms. For example, how can we foster the participatory and community feel of watching a live experience, but after the fact? In their work on the FANFEEDS prototype, Basapur et al. found that enabling viewers to read time synchronized comments while watching a television show, helped them feel more connected socially [123]. Other work has explored how to design asynchronous accelerated playback of live experiences to help participants catch up to real-time experiences that they have missed [183]. By working to simulate the social benefits of live media, we may advance the design of socially engaging asynchronous experiences.

7.3.4 Supporting New Live Experience Patterns and Roles

In Chapter 6, we identified a set of live experience patterns, based on our observations of prior live media platforms and how our participants used CLMC to support their courses. We discussed patterns included broadcasting, small team, and touring, each of which describes a distinct way of assembling media and organizing people around a shared experience. The affordances of the modalities assembled determine how people can share in the experience. How people can view, listen, or sense in some other way a live experience is determined by the modalities made available.

Modalities afford a specific way of participating through them (Section 7.1). Many people can type in cool text chat. Fewer can discuss in warmer push-to-talk. Even fewer can effectively participate through hot live video. How modalities are assembled directly determines how people can participate in the experience.

Further, people assume roles in live experiences. Some may lead the experience, such as streamers. Meanwhile, lurkers may just be watching. Others may be working in a more supporting role, e.g., stream moderators on Twitch often do considerable work to manage the stream community. The roles that people assume are determine through both ad hoc social articulation as well as system enforced structures.

For example, a friend of a live streamer may work out a personal agreement to help manage a voice chat room the streamer uses during their streaming sessions. The streamer may then give this person moderator privileges for the voice chat system, e.g. adding or removing participants, adjusting volume levels, or creating sub rooms in the system. In this case, there will probably be an informal agreement between the two about how these privileges should be used. Maybe, the streamer only wants community members that have been around for over a year to be added to the chat channel. The friend then has assumed a role of a secondary community leader, with the role of administering and moderating this aspect of participation in the stream community.

When we create new forms of live media, we can potentially create new ways for people to experience, participate in, and organize live experiences, i.e. new live experience patterns. Additionally, there will inevitably be new roles for people to assume. As researchers and designers, it is critical to think about how new live experience patterns will form. What are the social implications for a particular new form of live experience pattern? What are the potential roles that will be need to be filled in order to manifest these new experiences? How do communities decide who will fill these roles? How do we help people understand these new patterns? How can we help people leverage new media patterns to meet their needs?

7.3.5 Addressing Participation at Scale in Live Experiences

As we discovered in our qualitative investigations of Twitch (Chapter 3) and Live MOOCs (Chapter 4), scaling participation in large live communities is a recurring issue. For example, there are often too many viewers in the text chat of large Twitch channels to keep up with. Similarly, MOOC instructors have limited time to personally engage with every student.

We briefly review some of the approaches already being employed by the communities we have

reviewed. One primary way we observe that live communities address the issue of participation at scale is to gate participation behind a financial barrier. Twitch streamers will use "subscriber only mode", where only paying subscribers can talk in the text chat. MOOC instructors are considering only offering live learning experiences to students who pay an extra fee to take their course. This approach has the benefit of filtering for participants that have personally invested in the community. However, it fails to account for participants who have invested in other ways (e.g through time or volunteer work). This approach also significantly restricts the openness of live communities.

Another approach we observed was to recruit community members to engage with participants. In Twitch, regulars and moderators take it upon themselves to engage with viewers and promote viewer participation. In MOOCs, instructors recruit community TAs to work closely with students and engage them in participatory learning activities. These practices encourage a distribution of the leadership within the community and lead to the establishment of regular members who do the work of promoting community participation. This work in itself is a high-impact way of participation in the community. Future work investigating the design of tools to support identifying and recruiting these community members would help support participation at scale.

Beyond these existing practices, we argue that other media design approaches will potentially help. One approach, as we have already discussed, is the incorporation of a variety of cool, low-impact modalities. These modalities provide ample opportunity and space for peripheral participation, i.e. many people can participate using text chat or hearts. However, simultaneous incorporation of hotter modalities provides opportunity for the smaller group of intensely engaged participants to have more impact. We argue that providing for this continuum maximizes the participatory potential of a media space. Future work could examine how to help people create media spaces that incorporate cool and hot modalities to best support impactful participation at scale.

Finally, supporting smaller sub-groups within larger communities may help support broader, more participatory live experiences. As we observed on Twitch, stream communities would often watch larger streams together. This enabled viewers to still have a participatory experience with community members they identified with, situated around the context of a larger live stream.

Since our initial investigation, Twitch has actually developed a channel hosting feature, which has formalized this practice. In the context of Live MOOCs, we found that instructors often encourage students to participate in small participatory learning activities (e.g. pair programming or small group poetry readings). We hypothesize that encouraging participation through small groups within larger communities, especially groups that can connect around shared experiences and backgrounds, will provide more opportunity for impactful participation at scale. To this end, we will investigate and design new tools to help identify and foster small-groups with shared histories and social connections within large live communities.

Finally, we note that throughout the deployments of our live media probes, we were only able to investigate relatively small groups of participants. During our investigation of the rivulet probe we were able to recruit over 100 participants. However, this scale is still relatively small compared to in-the-wild live stream audiences. Future work would benefit from attempting to study new media designs in the context of at scale audiences with thousands if not tens of thousands of viewers.

7.3.6 Fostering Live Media Places

In Chapter 1, we discussed the concepts of space and place as introduced by Tuan [19], and Harrison and Dourish [20]. In Chapter 3, we observed how live media environments began to serve as third places [106] for communities to come together in and share experiences, discuss, and engage in sociability. A long term goal for this research is to support the establishment of live media places for online communities.

While the Rivulet and LiveMâché probes represent new media space forms, designed to promote participation in live experience, we were not yet able to investigate their efficacy in supporting placeness. This is primarily due to the short-term, formative way in which the probes have so far been investigated. Establishing a place takes time. A group of people must inhabit it. Routines and known practices must be developed by those people. The inhabitants rearrange the place, themselves, to suit their needs and reflect their values. Alexander notes that "every place is given its character by certain patterns of events that keep on happening there" [171].

Our design of CLMC was focused on enabling participants to arrange elements in order to

meet community needs. We wanted participants to be able to collaboratively restructure a live media space in order to help establish a place. However, there is more to a place than a temporary first time arrangement. In our investigation of CLMC, in the situated context of the landscape architecture course, we found that, over a period of four weeks, there were some initial signs of a place being formed. Routines were starting to be established. Students participated in a regular way through voice, video, and text chat. The instructor collected and assembled media before and during lecture to support his presentation. However, in one of the last sessions we started to observe instances of the instructor enabling the students to add their own media and sketches in the curation space. We expect that we would have seen more of these types of practices emerge given time.

Thus, in future work, if we want to observe how live media spaces may be adopted to create community places, we expect to need to deploy live media probes for a longer duration. Through these extended investigations, we expect that we will see how participants adapt to the media and how *they adapt the media* to suit their needs. We may see longer term impacts on community experiences and activities. Finally, through extended summative evaluation we expect that we can start to see how new forms may lead to the future of online community media places.

7.3.7 Addressing Live Media Harassment and Cultural Issues

While we have observed that live media supports new forms of participation and the formation of new communities, there are many potential issues that emerge in live media contexts. Live media, particularly live video, provides a view into the private lives of other people. This can be taken advantage of or abused fairly readily in some instances.

On Twitch, we have observed a variety of abusive behaviours occur. For example, *stream sniping* has emerged as a typical form of abuse on Twitch. Stream sniping refers to when a live stream viewer tries to find a way into the same multiplayer game as the streamer. The stream sniper then uses the extra information provided by the stream in order to gain an unfair advantage over the streamer. Stream sniping in this way is widely considered a form of cheating, and is grounds for being banned in some games. Alternatively, stream snipers will harass the streamer either

through verbal abuse through a game's built in communication channels or by directly hindering the streamer in game.

There are also far more sinister forms of abuse that have been enabled by live media. *Swatting* is a particularly dangerous form of online abuse, where a viewer uses some information gleaned from the stream to falsely accuse the streamer of committing some crime. Typically, the viewer will contact the authorities and make an accusation that the streamer is holding someone hostage or impersonate the streamer making a violent threat. This in turn often triggers an aggressive police response. Often the streamer ends up being confronted by heavily armed police. They must then explain that the threat the police are responding to is actually an ill-conceived joke. Often this whole series of events is broadcast over the live stream, to the gratuitous satisfaction of the abusive viewer. In one such case, swatting has resulted in the wrongful death of the streamer [184].

This type of behavior is rampant on Twitch, and is a source of great frustration and trepidation for streamers. The most effective way for streamers to reduce the risk of being swatted or harassed in some similar way is to limit personal information that can be gleaned from their stream. However, this can be difficult given that they are typically streaming a live view of themselves from their homes and potentially their desktop. Thus, it is easy for private information to unintentionally be exposed through these media streams. To combat this, streamers often use overlays to cover up parts of their stream's video. Unfortunately, it is hard to account for every piece of sensitive information that may be exposed. Designing tools to help live media users think about and obscure their personal information is definitely an area for future consideration.

Additionally, a number of cultural crises have recently emerged around live media platforms. The recent Gamergate controversy concerning the issues of sexism around gaming culture has been characterized by a variety of forms of online harassment. This controversy and relevant discussion has often played out in the text chat of Twitch live streams. Further, video game live streams on Twitch have long had problems with viewers and streamers engaging in different forms of sexual harassment and abuse [185, 186]. Racism and hate speech on live streaming sites has also been an ongoing issue [187].

More work needs to be done in order to start understanding all of the ways these kinds of anti-social behaviours are manifesting on live media platforms. These issues also bring up ethical questions that must be addressed. How do we as researchers ethically collect data about and report on abusive interactions? When is censoring and/or banning of people an appropriate response? How to best address these issues through both the design of media technologies and policy is still an open question that needs more investigation.

7.3.8 Games as Live Media

Our investigation into live media began with video game live streaming. In Chapter 2, we examined multiplayer games as a form of live media. They enable people to connect in real-time and participate in a compelling shared experience. While live streaming existed before, Twitch is arguably the first live streaming platform to be successful at such a large scale. Thus, we think that games and the experiences they afford may be at the core of recent live streaming phenomena. Given this, there is much potential future work that can be done to investigate how to improve video games as live media.

In some recent work, we investigated how games incorporate awareness cues to provide information about other participants [97]. As games shift from private to public experiences that are shared on live streams, it will become important to think about the information needs of viewers, not just the players. What real-time information will improve the spectating experience for viewers? Do visual and aural cues added to a game for the benefit of viewers lead to a better experience for the player? If not, is there a way that we as designers can address this differentiation in needs?

As we briefly mentioned in Chapter 2, audience participation games are designed to enable live viewers to participate. This is enabled by providing game mechanics that viewers can engage in through a modality provided by the live stream interface [76]. Typically, these have taken the form of a game that a streamer plays, but in which the viewers can have some peripheral influence. However, other games, such as those known as "Twitch Plays" games, are completely controlled by the viewers [188]. The most well known of these was the Twitch Plays Pokémon (TPP) game that emerged in 2014, which created a chat based system for controlling the original game Pokémon

Red. TPP was played by hundreds of thousands of viewers and also inspired a host of similar games. All of these audience participation games enable viewers to have more agency in the live game experience. Future work may look at new ways to incorporate viewer participation in gameplay. For example, instead of peripheral, unitized actions, viewers could theoretically take on the role of acting out characters in a game, participating through higher fidelity, more impactful modalities.

Video game live streams on Twitch and other platforms continue to be the primordial grounds for new live streaming experiences. Twitch communities are always changing, as streamers and viewers fluidly create new practices for sharing and participating in distributed experience. For this reason, we expect to return to investigating new forms of live media and participatory experiences in the context of video game live streaming.

7.4 Conclusion

In this work, we investigate new forms of live media and how they are enabling new forms of participation in online communities. Through qualitative investigations of situated live media contexts, we develop an understanding of practice and media impacts. Through our investigation of Twitch, we discovered how live streams serve as places for building community through participation in rich shared experiences. We recontextualize McLuhan's concept of hot and cool media as a analysis framework for understanding the participatory affordances of live modalities. We argue that live streaming enables participation and sharing rich experiences by combining hot and cool media.

Further, through a qualitative investigation of media use in MOOCs, we find that instructors are turning to live media to encourage students to participate in learning activities and build course communities. We found that instructors utilized a spectrum of hot and cool modalities to enable both highly engaged as well as lurking students to engage in learning activities.

Leveraging findings from our qualitative investigations, we design and evaluate media probes to examine the impact of new forms of live media. Through an at-scale deployment of the Rivulet probe, we discovered how combining multiple live streams with a spectrum of hot and cool modal-

ities enabled more impactful participation. We also found that bringing live streams together fostered a stronger sense of community among participants, bridging disparate social contexts.

Finally, we design CLMC to support the collaborative assemblage of live media to create participatory online places. We evaluated LiveMâché, a CLMC probe, in the situated context of online learning to investigate its impact on live learning activities. We found that instructors and students engaged in collaborative assembly of media as a new form of participation. We also examined how CLMC afforded a number of strategies for conversational grounding. Finally, we identified live experience patterns, manifest through use of CLMC and prior forms, and discuss how they may be supported through flexible assemblage of media and articulation of social roles.

Open questions remain. How do we support the amateur collaborative creation of live media? How do we support the creation of media places to support communities? How can we enable impactful participation at scale? How do we address the pervasive abuse of live media to harass and endanger people?

Despite these persisting questions, we expect live media will continue to rapidly evolve and transform how people engage with society. In future work, we will continue to strive to understand emerging live media phenomena and investigate how to support participation through new live media forms.

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