SUPPORTING CRITICAL COMPUTATIONAL LITERACIES THROUGH INTERACTIVE STORYTELLING

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Brigid Barron, Primary Adviser

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Paulo Blikstein

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Antero Garcia

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

Roy Pea

Approved for the Stanford University Committee on Graduate Studies.

Stacey F. Bent, Vice Provost for Graduate Education

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Abstract

This dissertation explores how pedagogical uses of interactive storytelling can support the development of youth critical computational literacies, in and out of school. Despite extensive documentation of inequities in K12 computer science education and numerous initiatives working to address them, we lack theoretical accounts and practical tools for how computing itself plays a role in marginalization and oppression. Meanwhile there are few opportunities for literacy educators and researchers, who are centrally concerned with the relationship between language and power, to participate in K12 computer science education. One barrier to interdisciplinary pedagogy and research has been the lack of shared constructs between literacy studies and the learning sciences. This dissertation proposes *critical computational literacies* as an interdisciplinary construct encompassing cognitive, situated, and critical scales of literacy practice, and the relationship of each scale of practice to the infrastructural media through which it is enacted. *Critical computational literacies* provides an account of *identity authorship* and *channeling voices*, two forms of critical action by which authors can transform literacies through participation to make room for their identities and for their voices. This dissertation focuses on a ten-week curriculum unit in a midwestern US sixth-grade classroom using Unfold Studio, a web application for reading and writing interactive stories written with a combination of prose and programming. Building on three years of participatory design-based research, this study used mixed methods to analyze how authors used affordances of text and code toward rhetorical and critical ends, how they

used interactive storytelling to connect across literacies, and the extent to which literacy participation was associated with computer science learning. One primary contribution of the dissertation is an articulation of *critical computational literacies* grounded in constructs and methods which are important to both the learning sciences and to literacy studies. I show that interactive storytelling can be an effective medium for supporting critical computational literacies which connect youths' existing literacy practices to the classroom, and which support critical action through identity authorship and channeling voices. Unfold Studio and its curriculum are practical tools for teaching with interactive storytelling. Finally, the dissertation offers a theoretical justification for a literacy-based approach to K12 computer science education which centers youths' lives and stories, with empirical evidence of its efficacy.

Acknowledgements

This dissertation is the culmination of five years of work and builds on numerous prior publications. Permissions have been secured when portions of prior publications are included in the dissertation. These were made possible by a broad network of people who were willing to invest their time, energy, resources, and confidence in me and in this research.

I am grateful to the students, teachers, and school leaders who have invited me into their learning environments. Unfold Studio was developed through a series of participatory design-based workshops; many of its features and now-fixed bugs are a result of feedback from students and teachers. Beyond making this research possible, some of these collaborations have grown into professional collaborations and enriching friendships. Thanks especially to Leif Segen, Corey Rogers, Erin Angell, Eric Bloom, Laura Reeve, Tricia Kellison, Sophie Libkind, Kylie Jue, Jacob Wolf and Jenny Han.

I could not ask for a richer group of mentors than my dissertation committee. Paulo Blikstein invited me into academia and has consistently held open the constructionist learning environments where people, tools, and powerful ideas come together, and where I have felt most at home in academia. His labs at Stanford and Teachers College have been dynamic intersections of disciplines, commitments, backgrounds, and languages. Antero Garcia has been an inspiring mentor, co-teacher, and co-author. I admire his commitment to the work of practicing teachers and the critical consciousness with which he acts, speaks, and remains silent. Brigid Barron has been a

constant supporter during the last turbulent years, a source of wisdom and good advice, pushing me toward more rigorous and ethical research, and to keep in mind the children who participate in and who will be touched by my research. Roy Pea has shared with me the history and developmental trajectory of our field, a regard for the longer arcs of thought spanning lifetimes, and how these threads manifest in the grammar linking sentences together. Learning sciences is what learning scientists do. Yasmin Kafai is not on my committee, but I am also deeply grateful for her mentorship, generosity as a writing collaborator, and for her warmth in welcoming me into her research group when I moved to Philadelphia two years ago. She and the other members of Penn's learning sciences RAC have been an inspiring community of practice and have offered invaluable feedback on several publications.

I am profoundly grateful to the members of my academic communities, including those at Stanford, the University of Pennsylvania, Teachers College, and the extended family of scholars whose company I have already come to eagerly anticipate at conferences. Without the camaraderie I share with lab mates Engin Bumbacher, Richard Davis, and Veronica Lin, I cannot imagine making it through the last five years. I would also like to thank the members of our community whose work has made our lab and my graduate career possible: Diana Garcia, Claire Rosenbaum, Jonathan Pang, Livia Macedo, and Kate McKinney, among many others.

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As I have immersed myself in the world of academia, I have sometimes failed to make enough time for my family and friends. I ask for their forgiveness for when I was not there for them, and hope I can make it up to them by being a gentler, more thoughtful, and more loving friend, family member, and partner in the years to come. The last five years have been overshadowed by mourning the loss of my father, who passed away shortly before I started graduate school, and who taught me how to use tools and computers. Between him and my mother, a tireless organizer and optimist in schools, local government, and nonprofits, there is very little surprise in the work to which I have committed myself. I look forward to growing and deepening my love for my brothers, their partners, and their families in the years to come. And all of this is grounded in, and comes into focus through my partnership with Zuz. She is the love and joy of my live, the co-creator of worlds we are stepping into together, with Rye and Canela somewhere out ahead.

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Introduction

In December 2013 I attended a memorial for Douglas Engelbart at the Computer History Museum in Palo Alto, California. In early evening the large auditorium filled with grey-haired men and women gathered to celebrate and mourn the passing of a man whose dreams of augmented cognition and computer-supported collaborative work helped open the age of personal computing. One by one, people rose to tell stories. We saw a clip from the "Mother of All Demos" in 1969, when Engelbart and his colleagues showed off a vision of computer-supported collaborative work with an overwhelming collection of inventions: video conferencing, collaborative document editing, new interfaces for computers, and new social structures. Although Engelbart's dreams are still alive among academics and inventors, they had long since faded from the popular imagination and no longer brought in grant money.

His family and friends and more recent collaborators told the story of Engelbart as a private person. Finally, Ted Nelson, the poet and inventor, author of *Computer Lib/Dream Machines* (1974), rose to speak. He read a poem, voice cracking and eyes red with grief. Then he turned to us with bitterness on his face. "You killed him," he cried, accusing an invisible constellation of the audience of building fortunes on Engelbart's dreams and then selling him out. They, Nelson accused, had taken Engelbart's intentions and adapted them to a far lower estimation of their users, trading augmented cognition for usability and instant gratification.

Other dreams have also lost their grip on our cultural imagination. Constructionism, Seymour Papert's vision of computers as tools children might use for thinking and learning, mediating and embodying powerful ideas, has been largely supplanted by an industrialized school lunch version of computer science: cheap and scalable but not what you would want served to your children. In his keynote address at the 2017 Interaction Design and Children conference, Andrea diSessa took stock of computational literacy, his dream of widespread computer-supported cognition and social practice which could transform human being almost as profoundly as the spread of print literacy. "What if your project's timeline is 100 years?" he wondered, a nod to the scale of the project but also to how far we are from its realization (diSessa, 2017). Even the Learning Sciences, a thriving field of academic research, have not realized its goal of transforming educational systems and practice. At the plenary session of the 2017 Computer Supported Collaborative Learning conference, leaders of the field raised eight essential questions for the field. Among them: "We should be honest with ourselves: if we have not managed to achieve any measurable impact by this point, why should we believe that we will be able to do so in the future?" (Wise & Schwarz, 2017) Historically, societies have aimed either at low levels of widespread literacy or high levels of literacy for a small elite, so the goal of substantial and widespread computational literacy is ambitious (Resnick & Resnick, 1977).

If the educational project of fostering widespread computational literacy has made little headway, our society's transition to computational media as the infrastructure of everyday life is nearly complete. We rely on computer systems to filter our news, connect

us with family and friends, keep track of our money, validate our credentials and legal status, keep us supplied with electricity, water, and food, and direct the use of military force. This is profoundly true for youth, whose pervasive use of computers mediates many of their relationships and powerful positive and negative experiences (Anderson & Jiang, 2018; Itō, 2010). Computers give shape to our worlds. But despite widespread evidence that our computational infrastructure is working toward the interests of the few with unintended effects causing widespread damage (Noble, 2018; O'Neil, 2017), everyday users have only a hazy understanding of how all this works (margolis2008; Geronimo, Braz, Fregnan, Palomba, & Bacchelli, 2020). Our widespread dependence on computational media is an opportunity for powerful computational literacy education; our widespread ignorance of computational media makes that education urgent.

However, there is widespread debate over what kind of computing education we need (Blikstein, 2018; Vogel, Santo, & Ching, 2017). In my view, the major challenge in developing K12 computer science education is that there is insufficient overlap between the research communities and theory of computer scientists and the K12 educators. Computer science, and the emerging field of computing education research, are largely composed of researchers whose expertise and lived experience is in university-level education. As a result, there has been a tendency toward a teleological view of K12 computer science education leading to a fixed conception of computer science as defined by academic and industry. Pedagogies focused on supporting prerequisite identities and communities of practice are sometimes illegible from this point of view, as are the needs and values of the diverse communities served by primary and secondary public schools in

the United States. The intellectual vibrancy and sense of possibility sustained by university-level computer science communities is not shared with their K12 counterparts when the latter are not included in shaping them.

I am interested also in expanding our understanding of K12 computer science in the same ways the idea of *literacy* was blown open by multiliteracies (The New London Group, 1996), opening computer science to more participants and a wider array of practices. The tremendous cognitive and situated richness that can come with computer science has in the past been limited to very narrow and privileged groups of people who were not always aware of the bubbles they lived in, or skilled in working to open them. This has led to ungenerous, sometimes insensitive efforts to broaden participation without interest or understanding of the identities, cultures, and agency of those who would be included, nor an awareness of what it means to hold on to power over the "definitional enterprise" of what kinds of practices count as legitimate (Scribner, 1984, p. 8). Broadening participation without sharing power is not liberatory. The goal of this dissertation, therefore, is to open space for new futures for computer science education, inclusive futures which youth becoming computer scientists participate in defining and which are oriented toward justice.

Structure of the dissertation

The dissertation is organized into seven chapters. Following this introduction is a background chapter providing a review of the literature grounding the dissertation as a whole, and which builds the conceptual framework shared by all of the results chapters (4-6). I develop the concept of critical computational literacies over several passes,

qualifying my use of "literacies" and then extending literacies into critical and computational dimensions. Each of the results chapters (4-6) builds on the background chapter with its own background section. These chapter-specific background sections tie the overall conceptual framework to that chapter's research questions, and frame the research questions in terms of the specific literatures to which they are salient and to which they contribute. As this is interdisciplinary research, those literatures and the communities of practice they represent vary somewhat from chapter to chapter.

Following the background is a chapter on methods. Since the dissertation as a whole is a multi-faceted analysis of one ten-week classroom study, I begin with a thorough introduction to the school and community context, the students and teachers involved, the curriculum, and the tools used during the study. I provide a detailed overview of Unfold Studio, the web application used and analyzed in the study, as well as Ink (Inkle, 2019), the programming language students used to write stories on Unfold Studio. Much of the data used in the analyses was produced through interaction with Unfold Studio.

Then there are three chapters, each focused on one of three primary research questions. These questions are organized by a conjecture mapping (Sandoval, 2014); one question explores how the design of the interactive storytelling platform produced changes in the learning environment salient to learning (Sandoval (2014) refers to these observable changes as mediating processes). The second and third questions investigate the nature of the learning which emerged from mediating processes. As with the background, each of these chapters contains its own methods section connecting to and

extending the overview provided in the methods chapter. Finally, I close the dissertation with a conclusion synthesizing the results and laying out my future research agenda.

Background

This literature review has three parts. It starts by constructing the concept of critical computational literacies from interdisciplinary sources, then zooms in on identity-authorship and voice, the two forms of critical change which are my focus. Finally, I review prior theoretical approaches to interactive storytelling and develop the analytical framework I plan to use. In each part I draw on prior work to define the constructs I will use in this research. I also discuss alternatives and argue for the framings I have chosen to use.

I begin by introducing literacy as a way of thinking about people, texts, and communication between them. I discuss how two different fields, learning sciences and literacies, have conceptualized literacies, and explain how thinking about literacies as figured worlds incorporates important perspectives from each. Then I consider the relationship between literacies and the media with which texts are written. Computational literacies, supported by computational media, support different kinds of cognition, social practices, and action from print literacies. Computational literacy practices substantially overlap computer science, and the debate over how to define computational thinking (or perhaps, computational literacy) is an effort to map the intersection. Finally, I define what I mean by critical literacies and consider the emergent field of critical computational literacies.

I am interested in literacies because they can support participants in developing criticality. In the second part of this literature review, I discuss what I mean by criticality

and identify identity authorship and channeling voice as two ways in which youth make room for themselves and make themselves heard. Among the many ways researchers have theorized identity, my priorities are those which are dialogic and which emphasize narrative. I see identity as something authored in the context of other stories which provide opportunities and constraints on who someone can be in a particular situation. In the field of composition studies, the concept of voice has undergone a similar dialogic development. Whereas previous ideas of voice emphasized personal disclosure and authenticity in writing, a dialogic perspective emphasizes finding one's footing in existing meanings so that in addition to speaking through writing, one's writing is heard. The writerly metaphor of voice suggests a close relationship between inscription and utterance. I close my discussion of identity authorship and voice by explaining why I choose to focus primarily on people's reading and writing, as opposed to their speech or their gestures.

Having defined the goals of supporting identity authorship and channeling voice, the third part of the literature review addresses the theoretical context of interactive storytelling and develops an analytical framework for how interactive storytelling could support critical literacy practices. I discuss prior work in interactive storytelling in popular and educational contexts, and literary theory which has been used to study interactive stories. I propose an analytical framework based on a chain of hypotheses: that the perceived affordances of a computational medium could shape the rhetorical practices for which it is used; that these practices could shape the identities and voices which are

thereby enacted; and that these identities and voices could open possibilities for critical understanding and activism.

Literacies

A good place to start building a definition of literacy is the way it is used in everyday speech: knowing how to read and write. This involves individual skills such as decoding, comprehension, and constructing an argument. However, being literate also means engaging in social practices which depend on reading and writing. For example, reading and writing allows people to write down contracts and laws, knowing they can refer back to them later. This makes it possible to coordinate action across time and space. We count on others to fulfill their end of the bargain because we know that if they did not, we could appeal to a legal system which would recognize the authenticity of the contract and enforce it. Similarly, being a law-abiding citizen (who could in principle consult the laws, and who will be held accountable for following them via a legal system based on literary analysis) depends indirectly on reading and writing. Broader social structures such as a public sphere (Habermas, 1991; Warner, 2002) or a nation (Anderson, 2006) also depend indirectly on functional individual reading and writing skills.

There is a limit to our ability to give a universal description of the structure of literacy. Scribner (1984) emphasizes that literacies themselves are situated. What constitutes a legitimate literacy practice, and the social rewards that come from participation, vary across societies. Part of what it means to be literate in the United States is to operate with the assurances described above–to assume the availability of economic participation, legal protection, and a receptive public ready to hear one's

opinions. Many people in the United States are systematically denied these privileges while simultaneously being defined as illiterate. Stuckey (1991) observes that literacy has historically functioned as a justification and mechanism for social class, defining peoples' worthiness of receiving disproportionate resources. Scott's (1998) analysis of how states impose legibility and Pikkety's (2020) discussion of states as "inequality regimes" both understand the essence of state power as framing and measuring in specific ways which enact and justify social hierarchies. Similarly, the United States has a long history of linking literacy with race, language, and immigrant status, so that marginalized people are defined as illiterate and therefore undeserving of social rewards and position (Rosa, 2019). It is common to meet immigrant doctors and lawyers working low-paying jobs in the United States because their literacies are not recognized.

The descriptions of literacy in the previous two paragraphs point to what makes literacies powerful and also difficult to study: they span units of analysis. Literacy includes individual cognitive processes, situated social interactions, and broader power relationships contextualizing communities of practice. Building on our conceptual work taxonomizing computational thinking in Kafai, Proctor, & Lui (2019), I find it helpful to think of literacy practices at three scales: the cognitive, the situated, and the critical, corresponding to individuals, communities of practice, and societies or cultures. Interactions with media transform practices at each of these scales. Figure 2.1 sketches these three scales of practice as nested circles within a plane, hovering above a second plane representing media infrastructure. Media infrastructure is composed of the technologies which enable and shape literacy practices. Figure 2.1 shows two axes

structuring literacy: the relationship between infrastructure and practice, and the relationship between practice at different scales. The learning sciences have been particularly effective at studying the relationship between infrastructure and practice and the relationship between cognitive and situated practice. Literacy studies have been particularly effective at studying the relationships between different scales of practice. While there are substantial areas of shared concern, the two communities have not been sufficiently in dialogue with one another (Bang, Medin, & Atran, 2007; Gutierrez & Larson, 1994; Moje & Lewis, 2007; Vossoughi & Gutiérrez, 2016). One of my long-term goals is to contribute to interdisciplinary work between these communities.

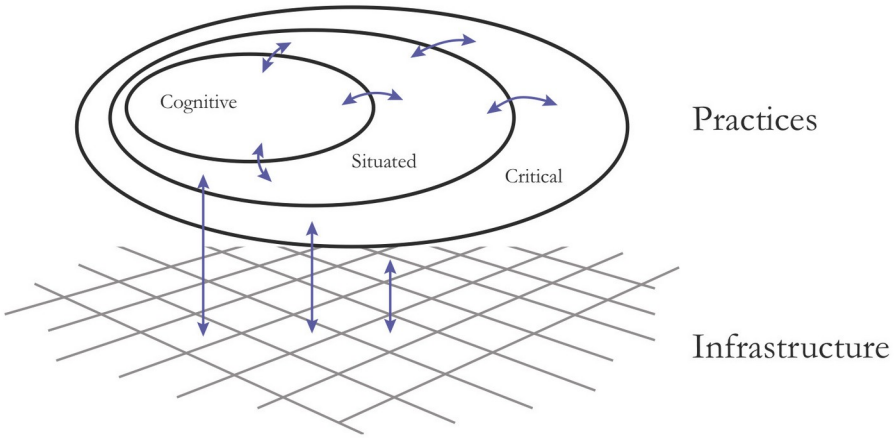

Figure 2.1: Two axes structuring literacy: the relationship between infrastructure and practice (vertical), and the relationship between practice at different scales (radial).

Literacy in the learning sciences

The learning sciences have historically been concerned with the mechanisms by which people think and learn with technology, individually and as participants in larger systems (Bransford, (U.S.), & (U.S.), 2000; Nathan & Alibali, 2010). While the greater part of literacy research in the learning sciences has been concerned with the cognitive mechanisms of processing printed text (Smagorinsky & Mayer, 2014), there has been substantial

Building on early socio-cultural theory, the learning sciences have produced functional accounts of literacy (diSessa, 2001), as well as complementary constructs describing how communities think and learn through interaction with media. These include distributed cognition (Cole & Engeström, 1993; Pea, 1993), activity theory, situated cognition (Brown, Collins, & Duguid, 1989; Collins & Greeno, 2011) and figured worlds (Holland, Lachicotte Jr, Skinner, & Cain, 1998). Within these theoretical frames, design-based research (Bang & Vossoughi, 2016; Collective, 2003) develops new technologies to understand and improve learning. These include Logo (Papert, 1980), diSessa's Boxer (diSessa, 2001), and more recent computational media (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Resnick et al., 2009; Sipitakiat, Blikstein, & Cavallo, 2004).

One strand of learning sciences work specifically focused on literacies started with S. Scribner & Cole (1978)'s studies on the cognitive and sociocultural effects of literacy in society. Scribner and Cole found that literacy (distinguished from schooling) was associated with changes in individual cognition such as improved abstract

communication, memory, and language analysis skills (1978, p. 456-457), though the effects appeared to be situated in specific contexts. Consequently, Scribner & Cole argued for the necessity of considering the mechanisms of literacy together with their context: "If, as we have demonstrated, particular skills are promoted by particular kinds of literacy practices, we need to know a great deal more about just how literacy is practiced" (p. 459). This is the argument for why Figure 2.1 needs to include both the horizontal and vertical axes.

Vygotsky provides the essential link tying these axes together. A central claim throughout *Mind in Society* (Vygotsky, 1980) is that cognitive functions begin as external, usually interpersonal processes and are then internalized. As they are internalized, they become conscious in a process parallel to that of concept formation as described in Thought and Language (Vygotsky, 1964). Deictic speech initially co-occurs with deictic gesture. Then, "the greatest change in children's capacity to use language as a problem-solving tool takes place somewhat later in their development, when socialized speech (which has previously been used to address an adult) is turned inward" (Vygotsky, 1980, p. 27). As development progresses, the child is increasingly in control of the framing: "For the young child, to think means to recall; for the adolescent, to recall means to think." (p. 51) For Vygotsky, the internalization of interpersonal practices co-occurs with increasingly intimate appropriation of the media. Thinking with computers becomes computational thinking.

Another strand of literacy research in the learning sciences addresses the ways in which computational mediation shapes individual cognition and social practice. diSessa

(2001) provides a clear-cut definition of literacy suited to studying the relationship between practice and infrastructure: "Literacy is a socially widespread patterned deployment of skills and capabilities in a context of material support (that is, an exercise of material intelligence) to achieve valued intellectual ends" (p. 19). He analyzes literacy in terms of three pillars: the material, (knowing how to interact with the medium) the cognitive (new ways of thinking supported by interaction with the medium), and the social (roles and structures supported by the medium). diSessa begins by arguing that pivotal moments in the history of science were catalyzed by new representational technologies such as algebraic equations. The historical importance of media in supporting distributed cognition justifies interest (and concern) in how computers might support new kinds of literacies. For example, there is widespread speculation that social, responsive, and networked digital media have given rise to new forms of reading and writing, changes in cognition (shorter attention spans; simultaneous address of many audiences), and disruptions to social institutions such as news and a broadly-shared belief in scientific reality. For diSessa, both cognitive and social aspects of literacy depend on material intelligence, or knowing how to make use of the infrastructure. I view diSessa's cognitive material intelligence and social material intelligence as describing the two leftmost vertical arrows in Figure 2.1. Material intelligence could easily be expanded to include critical material intelligence, or efforts to understand and change oppressive power relations which may be intrinsic qualities of digital media (Cohen, 2017; Eubanks, 2018; Noble, 2018; O'Neil, 2017). diSessa's call to think about computing in terms of

literacy has recently generated new interest in the context of computational thinking, which I discuss in the subsequent section on computational literacies.

Literacy, in the model developed above, is a configuration of practices at different scales, interacting with and shaped by an infrastructural medium. When I refer to a particular instance of people and texts, engaged in certain practices (such as the classroom I studied at Harrison Middle School) I will use the term "literacy place." Harrison & Dourish (1996) distinguish between space as "the opportunity" and place as "the understood reality" (p. 1). In contrast to *space*, *place* "denotes the ways in which settings acquire recognizable and persistent social meaning in the course of interaction" (Dourish, 2006, p. 299). This definition fits very well with literacy as a figured world (discussed below), as both are essentially concerned with social meaning-making. I use *literacy place* instead of *literacy community* because, as Gee (2008) notes, *literacy community* suggests a relation of membership amongst participants, when actually some people may unwittingly become part of a literacy place by virtue of being talked about. *Place*, as opposed to *space*, also connotes

New Literacies

A second major body of literacy research is grounded in practice, pedagogy, and research on writing. This community has been called "New Literacy Studies" (Street, 2003), as well. This community focuses on "the recognition of multiple literacies, varying according to time and space, but also contested in relations of power" (p. 77). The field is also called multiliteracies (The New London Group, 1996), a term which draws attention to "the multiplicity of communication channels and media, and the increasing salience of

cultural and linguistic diversity" (p. 63). Because of its focus on understanding and confronting power, the field is also called critical literacies. In addition to contesting the hegemony of dominant literacies, critical literacies aim to re-value marginalized literacies as legitimate meaning-making processes in and out of school (Morrell, 2015; Paris, 2011). I will simply use the term literacies. Literacies stands in a figure-ground relationship with the learning sciences approach to literacies, emphasizing sociocultural issues of identity, voice, and power rather than attempting to recover an objective stance while studying situated learning.

I draw on the field of literacies because it provides theory and methods for studying communities of literacy practice as sites of power, and how participants can change them. Moje & Lewis (2007) describe critical sociocultural analysis of literacy as focused on the production, transmission, and use of power in and around discourse communities. Similar to many approaches in the learning sciences, Moje & Lewis draw on Lave & Wenger (1991) to define learning as participation, but their interest is in the relationship between participation and power: "However, what Lave and Wenger were less explicit about is the idea that learning provides access to and control of Discourses—or ways of knowing, thinking, believing, acting, and communicating—that may be used to control the activity and material goods within a community" (pp. 3-4). This observation draws on Vygotsky's theory that as social practices are internalized, the learner gains more control over them, but Moje & Lewis draw out the implications for power and its material consequences. The rules guiding social practices become important concepts for thinking about power in sociocultural contexts because they affect

opportunities to participate (subject positions) and recognized forms of participation (genre). I address both of these concepts in greater detail below.

For educators, the recognition that dominant literacies also marginalize and disempower requires a commitment to criticality and ultimately action. Unfortunately, the adjective *critical* is used so often that it can be difficult to know what is meant. Freire (2000) sees the difference between "ingenuity" and critical thinking as "between knowledge resulting from pure experience and that resulting from rigorous methodological procedure," the latter allowing thinkers to become "epistemologically curious" (p. 17). Freire's (2000) political activism teaching the poor to read was grounded in a recognition that text-mediated thought was responsible for constituting them as passive subjects incapable of action. Learning to read the wor(l)d means participating in social meaning-making instead of taking meaning as given, realizing that the present world is constituted in certain ways and could have been different, and working toward more just and inclusive futures.

Freire's work illustrates two kinds of critical thinking I will focus on specifically in this research, which are aligned with the two axes I described in Figure 2.1. The first kind of critical thinking involves questioning the context, asking what power relationships led to some arrangement instead of others. I see this as moving out along the radial axis of practice. The second kind of critical thinking involves questioning the meaning-making processes at work. For Freire, and for critical discourse theorists such as Fairclough (2012), this means becoming aware of how textual meaning-making

functions. As described above, movement along these two axes are linked, and both are connected to power.

Literacies as figured worlds

The previous two sections reviewing literacy scholarship in learning sciences and literacies surfaced important features of each. Holland, Lachicotte, Skinner, and Cain's (1998) *figured worlds* accommodate both, which is why they are the primary construct through which I propose to study literacies. Figured worlds are "a socially and culturally constructed realm of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" (p. 52). The central theoretical innovation of figured worlds is an integration of the theories of Vygotsky and Bahktin. Holland, et al. describe a process of "symbolic bootstrapping" (p. 38) or "heuristic development" (p. 40) by which actors take up external tools (or ideas or symbols), use them, internalize them as part of their developmental histories, and thereby render their environments useful or meaningful in new ways. The pattern for this process is Vygotsky's (1980) account of how people acquire language and build concepts. For Holland, et al., Bakhtin's (1981) *heteroglossia* —the recursive composition of meaning from prior meanings—runs parallel to the Vygotskian process of tool and concept construction. A point Vygotsky, Bakhtin, and Holland, et al. emphasize is that the generation of new meanings is grounded in and constrained by existing materials which always have histories. Each participant acts from a history of participation which encodes the meanings of other actors, and so continued participation sustains the historical meanings of the system. This account addresses both

axes of literacy described in Figure 2.1. The vertical axis, linking practice with infrastructure, is addressed by Vygotsky's theories of symbolic mediation and internalization of social practices. The horizontal axis, spanning levels of context, is addressed by Bakhtin's dialogic conception of meaning.

Holland et al.'s account of figured worlds supports appealing conceptualizations of identity and agency. They view identity as a model of selfhood one authors and occupies in a literacy place, which exists at the interface "between intimate discourses, inner speaking, and bodily practices formed in the past and the discourses and practices to which people are exposed, willingly or not, in the present" (Holland et al., 1998, p. 32). Drawing again on Bakhtin's dialogic self, Holland and colleagues describe identity as the negotiated meeting place of unconstrained inner speech and an external subject position made available by social meanings. The subject position specifies the terms by which one is addressable and by which one will answer. "What we call identities remain dependent upon social relations and material conditions. If these relations and material conditions change, they must be 'answered,' and old 'answers' about who one is may be undone" (Holland et al., 1998, p. 189). Figured worlds also provide a dialogic account of agency, or the possibility of action within and possibly beyond figured worlds. Both identity and voice (a specific form of agency) are addressed in much more detail below.

Figured worlds are a particularly compelling frame for literacy because they relate the structure of the discourse community to the structure of narrative. Both are "collectively-realized 'what-if' realms," places where participants can author identities for themselves (Holland et al., 1998, p. 49). Perhaps the reason for this structural

similarity is that Vygotsky and Bakhtin, the two main theoretical sources of figured worlds, were originally interested in literary theory. Holland et al. write "Fantasy and game play serve as precursors to participation in an institutional life, where individuals are treated as scholars, bosses, or at-risk children and events such as the granting of tenure, a corporate raid, and the self-esteem of at-risk children are taken in all seriousness" (p. 51). Recognizing the correspondence between word and world is an essential Freirian critical move. The possibility of authoring figured worlds with new interactional possibilities is a central motivation for my exploration of interactive storytelling.

The concept of figured worlds has been used extensively in education literature. Often figured worlds are used to articulate a practice-based conceptualization of disciplinary learning. Identity authorship within a disciplinary world like mathematics has been used instrumentally, to help students become proficient in content (Jurow, 2005) or to transform ideas about what constitutes the discipline and how to teach it (Boaler & Greeno, 2000). Rubin (Rubin, 2007) documents how the figured worlds of urban high schools produce identities of incompetence and inadequacy. Hull & Greeno (2006) use positional identity authorship within figured worlds to argue for an ecological perspective on school, "that school should be understood as being supplementary to students' out-of-school worlds." (p. 78) A special issue of the Urban Review was devoted to the use of figured worlds in education. In the introduction, Urrieta (2007) identifies four primary lines of education research emerging from figured worlds: identity production, broad sociocultural constructs such as smartness, school, and family (Luttrell & Parker, 2001),

the success or failure of schools to support disciplinary identity development, and creating worlds of possibility.

Computational literacies

There are many reasons to teach computing in K12 education (Blikstein, 2018), but the last decade's surge in interest in K12 computer science education has been driven (and funded) primarily by the argument that our society needs more computer scientists and that becoming a computer scientist offers youth upward mobility. Consequently, K12 CS implementations have tended to prioritize skills-based approaches. Nevertheless, computing touches every aspect of our daily lives. This is particularly so for youth, who almost universally participate in social media (Anderson & Jiang, 2018) and rely on digital media for a variety of social purposes (Boyd, 2014; Itō, 2010). Wing (2006) proposal of computational thinking as the core thought processes characteristic of computer science, but broadly-applicable to school and everyday life, sparked an ongoing controversy over how computational thinking ought to be defined (Council & others, 2010; Grover & Pea, 2013).

Kafai et al. (2019) recently categorized the current landscape of computational thinking in terms of three frames: cognitive, situated, and critical. Table 2.1 describes how each conceptualizes learning at a different scale, and adopts corresponding epistemologies and educational priorities. These framings are of course perfectly aligned with the conceptualization of literacy presented above, and we close by considering recent calls to reconceptualize computational thinking as computational literacy. Computational literacy would not resolve theoretical debates within computer science

education, but it could help make different perspectives legible to each other. “If the CS education research community is to profit from this shift, literacy ought to be used as the basis for dialogue, not internecine battles. Scribner (1984), writing in the context of the so-called ‘literacy wars’ between advocates of phonics and contextualized whole-language instruction, chose to discuss literacy in terms of metaphors instead of definitions. Like Sfard (1998), Scribner argued that "conflicts and contradictions are intrinsic to…an essentialist approach" (p. 7). Adopting a literacy perspective means having to acknowledge the normativity and positionality of one’s project, which may not come easily to a community predominantly trained as academic computer scientists.

Table 2.1: Three framings of computational thinking (Kafai et al., 2019)

Frame	Unit of Analysis	Epistemology	Priorities	Computational Thinking
Cognitive	Individual learners	Skills, knowledge, competencies,	Measurable, transferable skills, economic opportunity	Computational concepts (algorithms, abstraction) and practices (remixing, iteration)
Situated	Communities of practice, activity systems, learning ecologies	Practices, participation	Equity, interest, identity development, creativity	Creating personally-meaningful applications, building communities, supporting social interactions, play
Critical	Society at large: existing structures of power, privilege, and opportunity	Critical consciousness Social action	Justice, critical understanding, enacting social change	Understanding and critique of existing computational infrastructures, creating applications to promote thriving, awareness, and activism

We were not the first to propose reconceptualizing computational thinking as computational literacy. There have been numerous calls for computational literacy from the learning sciences (Berland, 2016; Burke, O'Byrne, & Kafai, 2016) and literacies (Lynch, 2019; Vee, 2017). diSessa's (2017) keynote address at the Interaction Design and Children conference, Shum's (2018) keynote at the International Conference of the Learning Sciences, and Guzdial's (2019) keynote at ACM SIGCSE (Special interest group for computer science education) all addressed computational literacy. diSessa's address was an evaluation of progress made on what he imagines as a 100-year project comparable in scope to the early modern adoption of movable type. Shum focused on the infrastructural role of technologies in supporting social change. Guzdial put the transition in historical context, and emphasized the ways computation changes interdisciplinary and informal practices. Jacob & Warschauer (2018) "define computational thinking as a new form of literacy by integrating well-known literature on computational literacy, new literacy studies, new media studies, and computer literacy. Specific social, cognitive, and material features serve to distinguish this new form from other types of literacy" (p. 1), and pose a question which is one of my research questions: to what extent do literacy practices support the development of computational thinking?

This latter question, specifically, the way computational thinking related to power and positionality through dialogic identity-authorship and voice, has not yet been substantially addressed. There is a wealth of important research on equity and inclusion in computer science (Barron, 2004; Kafai & Peppler, 2011; Margolis & Fisher, 2003; Margolis et al., 2012), but it has generally been framed in terms of learning ecologies,

participation, and interest development rather than literacies (Barron, 2006). I see the two framings as complementary but not duplicative. I see the former as focused on the "outside" of literacy, on its social purposes and effects, rather than at the meaning made within and through texts. I am looking "inside" at how it works–in context, and at various scales. Though I do not adopt his terminology, Street (2003) draws a parallel distinction between literacy practices (which he defines as "social practices and conceptions of reading and writing") and literacy events, defined by Heath as "any occasion in which a piece of writing is integral to the nature of the participants' interactions and their interpretative processes" (1983, p. 93). The difference is also visible in my methods: I propose to make textual-computational texts central in my analysis, with speech, gesture, and other embodied discourses providing interpretive support. In contrast, scholars such as Itō (2010) prioritize the discourse and ecological relationships surrounding media over texts themselves. (p. 4) I hope this research, with its focus on reading and writing narratives encoded in texts, contributes to broader accounts of learning ecologies.

Nearly every article I have read which addresses computational literacy makes a distinction between *literacy* as framed above–as cognition mediated by external semiotic media, deepened by situated and critical practice–and *literacy* construed in the narrowest possible sense, as a synonym for passing familiarity, knowing how to use a web browser and a word processor. I will make this distinction as well, because I frequently see a cursory treatment of *computer literacy* or *digital literacy* included on curricular standards. The narrow sense of literacy is more concrete, it is easier to teach and assess, it requires no background in computer science, and it sidesteps the political and ethical

aspects inherent to literacy. For example, New York State's draft K12 Computer Science standards define *digital literacy* as "the ability to use digital technologies to create, research, communicate, collaborate, and share information and work." (New York, 2020, p. 10). The definition notes that *digital citizenship,* or "understanding and acting in safe, ethical, legal, and positive ways in online environments," is part of *digital literacy* and explains that literacy is a lower level of understanding and skill below fluency. These profoundly inadequate definitions will contribute to an oppressive experience of education for those who seek to understand and confront injustice.

Critical computational literacies

If computational literacy is beginning to be taken up by computing education research (albeit still without much empirical work), critical computational literacies are just arriving. Lee & Garcia's (2014) design-based research frames critical computational literacies in terms of composition and connected learning. Lee & Soep (2016) argue for critical computational literacy as a pedagogy of resistance which "provides a way to create and theorize conditions for the potent learning that can take place at the intersection of engineering and computational thinking on the one hand, and narrative production and critical pedagogy on the other" (p. 481). This framework draws on Paris's (2012) critique of culturally relevant pedagogy, asking to what extent progressive pedagogy actually results in changed material conditions for students. This is a counterpoint to my focus on critical change through semiotic mediation, and helpfully raises the question of whether and when the people we aim to serve actually experience improvements as a result of transforming literacy practices.

What might computational thinking mean from the perspective of critical computational literacies? Most formulations of computational thinking identify an essential abstraction of what it means to do computer science and propose extending it to communities of practice which are distal from dominant high-status computer science practice in industry and academia. Definitions vary in terms of what is essential about computer science, as well as what kind of distance computational thinking is to traverse (e.g. early childhood, marginalized identities, interdisciplinary contexts), but what these definitions have in common is that they begin from and privilege dominant communities of practice. Vakil (2018) identifies hegemonic attitudes and practices in mainstream computational thinking (including situated equity-oriented approaches) and proposes a critical justice-centered approach. Additionally, numerous researchers have applied critical literacy practices from other fields to computation. Sandoval's (2017) ancestral computing refigures computation in terms of Xicana cultural practices, similar to Bang, Medin, and Atran's (2007) refiguring of school-based science in terms of indigenous epistemologies. Thomas & Stornaiuolo (2016) consider restorying in digital texts and Vogel, Hoadley, Ascenzi-Moreno, & Menken (2019) explore translanguaging in the context of programming.

The alternative is to start with learning in place, to presume the legitimacy of emergent practices of cultures and identities. But surely not all practices involving computers can be called computational thinking, much less computer science. Advocates of K12 computer science have spent decades trying to distinguish their field from the kinds of *digital literacy* courses I criticize above. Once again, this issue has a well-

developed parallel discourse within English/Language Arts pedagogy, questioning whether to teach dominant language practices as part of the culture of power, and who should make that decision (Delpit, 1988). Just as there is no Standard English in practice (rather, Standard English indexes the ever-shifting norms of those in power), there has never been a standard computer science. In fact, computer science is constantly ingesting new computational practices, and emerging stars such as startup founders are celebrated precisely for being disruptive. . Defining computer science is always going to be messy; designing computer science education is always going to be political. I propose that we celebrate and support every school community's work defining and designing computer science (Proctor et al., 2019).

Dialogic criticality

The previous sections built the concept of *critical computational literacies* layer by layer. This section will zoom in on several mechanisms by which literacies operate, so that I can be specific about the kind of change I hope to support. Returning again on literacies as figured worlds (Holland et al., 1998), I want to focus on what gets *figured* and how. When someone participates in a figured world, they author and occupy an identity, an operational model of selfhood which is always constrained by subject positions defined by existing social meanings. Concretely, when you walk into a coffee shop or pick up a newspaper, you are positioned and addressed in certain ways before anything starts. You may be gendered or indexed in terms of race or social class, identified as belonging or not belonging, threatening or nonthreatening, worthy of a certain level of respect and entitled

to do and say some things and not others. When we participate in a literacy place, we are interpreted or *figured* in terms of an identity.

A parallel process of figuring or interpretation takes place with texts, and here I understand texts broadly, to include books, images, tweets, cars, ideas, or anything that is treated as representing meaning. An apple is a text if it means something within a literacy place. Perhaps it was offered as a gesture of kindness or it was carelessly forgotten or it was the subject of an argument over whether to buy organic. Texts like books have iconic meanings (e.g. what it signals to read Shakespeare on a bus) which is figured by the literacy place in which they are contextualized. Shakespeare (the body of work) might be understood to be profound, colonial, boring, pretentious, or queer, and what it means to carry a copy of Shakespeare depends on what the text is understood to mean.

Texts such as books also contain codes (letters printed on a page) which can be made meaningful through reading, and the process of reading itself is also figured. Following Bakhtin, the term I will use for meaning-making processes (or modes of reading) is genre. Genre denotes the conventions according to which a text is read. Trying to read a text without understanding its intended genre can be confusing. Bahktin extends *genre* to include *speech genres*, or modes of discourse, which work in the same way. If you are not familiar with a speech genre, or misinterpret which genre is operative, a joke can be understood as a threat or an emotional bid to reconnect can be understood as an admission of guilt. I will use the term *genre* in an inclusive way, also referring to modes of meaning-making in multiple literacies. For example, various social media platforms have incubated distinct genres which are recognizable even beyond the platforms

themselves. One dominant genre on Instagram prioritizes a highly-polished aesthetics, expressing taste through a choice of visual filters. In this genre it is understood that everyone is engaged in superficial self-commodification to some degree, such that it is normal to ask for likes and it is important not to come across as too earnest.

Genre and subject position are closely linked, as genres often imply social roles and particular relationships between participants. And just as subject positions circumscribe the possibilities for identity, genres circumscribe the possibilities for *voice*, a distinctive mode of expression closely linked to identity. If identity is who you are, voice is how you talk. Subject position is to identity as genre is to voice. The analogy extends to space and place: one is the structure, offering and circumscribing possibility, and the other is the instantiation. Table 2.2 summarizes the parallel relationships between these concepts. To fill out the third column, I suggest *worlding* as the process of creating new places in space.

Table 2.2: Parallels between forms of critical action

The opportunity	Its instantiation	Enacted through
Subject position	Identity	Identity authorship
Genre	Voice	Channeling voices
Space	Place	Worlding

The political and economic processes of our world are increasingly mediated by symbolic systems. Consequently, I believe that the social distribution of goods and opportunities is increasingly mediated by literacy, and that a central means of wielding power is by shaping subject positions and genres, who people can be and how they can talk. As a concrete example, the central thesis of *Stamped from the beginning: The*

definitive history of racist ideas in America (Kendi, 2017) is that the purpose of race is to justify slavery. Kendi chronicles the long history of efforts to define who is Black, what it means to be Black, and how Blackness can be talked about so that slavery could only be seen as natural and just. Kendi also chronicles the history of antiracism, efforts to understand and undo race, redefining Blackness to allow the enactment of new identities and voices. This is the critical action I am most interested in studying in this dissertation: the ways in which authoring identities and channeling voices can transform the very oppressive subject positions and genres which constrain them. I extend these processes into critical computational literacies, the figured worlds in which I hope to support youths' development. In the sections below, I explain what I mean by identity authorship and channeling voices, drawing on previous work from Literacies and the Learning Sciences.

Identity authorship

The concept of *identity* was introduced in the discussion of figured worlds above, and I will rely on Holland et al. (1998) for a primary definition of identity. To recapitulate, I view identity as a model of selfhood one authors and occupies in a literacy place, which exists at the interface "between intimate discourses, inner speaking, and bodily practices formed in the past and the discourses and practices to which people are exposed, willingly or not, in the present" (Holland et al., 1998, p. 32). The idea of identity as an interface is important to me, that identity is a contact zone between the inner self and part of the outer world. I view the relationship between identity and subject positions as analogous to the relationship between place and space. Subject positions provide footing

for identity (Agha, 2005), traction for staking out who you will be in terms of categories such as race, gender, status, and role. I am interested in helping youth find ways of subverting subject positions which are oppressive because they are too narrow or because they are inherently marginalizing, but I do not believe subject positions are inherently oppressive, not that getting rid of them altogether is an incoherent goal. We would be lost without terms of engagement.

Also important is the idea that identity is performed or enacted in context. Identity considered as interface benefits from the way *interface* is used in computer science, as a protocol making systems compatible with one another, but rather than being fixed and predefined, social identity is constantly renegotiated. An interface, for computers or for people, only exists to the extent that it is recognized, and power is the capacity to recognize, address, to hail (Althusser, 2006). I am drawn to Butler's (Butler, 1997) ambivalent, dialogic view of power as subjection, which recognizes Foucault's (2012) and Althusser's (2006) sense of power as subject-forming, but which also recognizes what exists prior to being constituted as a subject, or perhaps within one's subjectivity (Holland et al. (1998)'s "intimate discourses, inner speaking, and bodily practices"). I understand identity as the "painful, dynamic, and promising" (p. 18) interaction between subject-forming external power and interiority "wavering on the horizon of social being" (p. 30).

I prefer the verb *author* over *perform* or *enact* for several reasons. First, authorship suggests an audience and membership in a community of practice. You are an author when you are ex cathedra in your literacy place, whatever else you might be in

other spheres of life. Identity authorship means crafting who you will be in a literacy place, where agency may be possible (having or gaining authority) but where power is also exercised through the shaping and maintenance of subject positions (being authorized). Authorship implies a creative process, and there are ancient associations between authoring stories and authoring self. And while I do not deal much with embodiment, I feel that the media infrastructure of literacy–the pen and paper or social media interface–determines the kind of being we can have in a literacy place. Being an author means having a deep relationship with the stuff of literacy.

Identity has been a central concept in literacies as well as in the learning sciences, with substantial overlap between each field's usage. In their review of identity in the field of literacies, Moje & Luke (2009) find several qualities common across definitions of identity: that identity is understood to be social, fluid, and recognized. "An identity depends on the individual's understanding (or lack of understanding) of how that identity will be recognized in that relationship, time, or context. The person is called into an identity by the recognitions or assignments of others, and the meanings the person makes of the identities available to him or her serve to constitute a sense of self or subjectivity" (Moje & Luke, 2009, p. 419). This description fits well with the way I think about identity. Moje & Luke (2009) analyze five metaphors for identity: identity as difference, identity as sense of self, identity as mind, identity as narrative, and identity as position. Of these, the account I have been developing of *identity as interface* mediates more internal and more external accounts of identity. While I want to avoid hard distinctions, I see identity as position and as difference are more externally-focused, addressing the

ways on how identity places us and makes distinctions which contribute to the definition of subject positions. I view identity as sense of self and as mind as more internally-focused, on a phenomenological account of what it is to experience being and subjectivity. I make very little attempt in this dissertation to articulate what may be on the internal side of the interface, though this is an area I am interested to explore in the future. In the conclusion, I consider Olson's (2016) proposition that mind is a self-referential symbolic system or, in short, that mind *is* interface.

Accounts of identity in the learning sciences are particularly helpful for theorizing the interior structure of the private-social interface I have been calling identity. Theories of identity in the learning sciences often work within Vygotsky's paradigm of learning as internalization of social practices. Sfard & Prusak (2005) define identity as "reifying, significant, endorsable stories about a person," emphasizing that identities are not expressed in stories, but are themselves stories (p. 14). Identity-as-stories is similar in many ways to identity-as-interface. Sfard & Prusak (2005) describe identities as "man-made and as constantly created and re-created in interactions between people" and which centers the same debate about the balance between individual agency and subject-forming power discussed by Butler (1997). Sfard & Prusak (2005) argue for identity as a more useful analytic construct than learning precisely because it functions as an interface. They critique constructs such as beliefs and attitudes as presuming a stable, "real" version of a person which a particular analysis might or might not accurately describe. They make a related critique of viewing narrative as revealing identity, because this framing again presumes an authentic but inaccessible version of self.

While I prefer to talk about identity as interface rather than identity as narrative, I recognize a functional similarity between identities and stories: you can ask many of the same questions, and do many of the same things with identities and with stories. The parallels between the structure identity and story are why stories and storytelling are such useful tools for identity-related critical change. My design-based research has mostly engaged with identities on a short time scale (days and weeks rather than months and years), so while I recognize the importance of identities' historical trajectories, I do not make use of Sfard & Prusak's concept of designated identities which develop over time, Gee's (2001) identity trajectories, or Markus & Nurius's (1986) possible selves. The decision to focus on shorter time-frames was partly forced by considerations of what was feasible to research, but also by my sense that identity really is an ever-shifting performance which, when it is stable over time, is more attributable to stability of context and practices of self-narration than about the accretion of a durable character (Mishler, 2004).

Channeling voices

Identity and *agency* have often been paired together, even though much of the work defining identity in the previous section was aimed at addressing problems with agency. In order to study and support youth enacting critical change, agency cannot be unconstrained (this erases social forces of oppression) nor rendered impossible by asserting the dominance of hegemonic subject-forming power. A dialogic account of agency is needed to go along with the dialogic concept if identity authorship developed above. The term I use for this is channeling voice.

Voice has been an important concept in critical literacies (initially in the writing classroom and then more broadly), naming qualities of presence and power we seek to support in students (Cook-Sather, 2006). However, since the 1980's, voice has been usefully critiqued and refined, so we need to be clear about how we are using the term. One problematic conception of student voice imagines each student to have a stable, authentic self, so that the pedagogical task is encouraging students to share (Kamler, 2003; Lensmire, 1998). The risk in emphasizing the sharing of authentic experience through writing, rather than how the writing is crafted, is that we may create inequities in which experiences we value and in which students feel safe sharing their experiences (Grumet, 1990). For example, this plays out in college admissions essays, where some students learn to cultivate experiences (volunteering, travel, transformative personal challenges) they can deploy as cultural capital while others feel exploited by pressure to reveal the hardships they have undergone or to allow themselves to be presented in terms of socially-valued diversity. More pragmatically, focusing voice on authentic experience recounted in writing pushes important issues to the background. The craft of writing loses focus, encouraging students to feel like voice is something some students possess and others do not. Important questions about who gets to speak, who gets heard, and how speakers get positioned–questions of central critical importance–also disappear.

If we want to focus on these questions, we need an understanding of voice defined in relation to in its context. This is sometimes described as a dialogic conception of voice, referring to the way everyday speech can only be understood as part of dialogue. Everyday speech is spoken by someone, to someone, in response to what was said before,

and with an awareness of what might be appropriate or expected. Ivanič (1998) understands writing dialogically, as "an activity in which people align themselves with socio-culturally shaped possibilities for selfhood, playing their part in reproducing or challenging dominant practices and discourses, and the values, beliefs, and interests which they embody" (p. 32). Supporting student voice then becomes a more substantial project: we need to help students construct identities from which to speak, take up and use the language around them, and recognize the voices already present in the words they use. As a strategy for enacting concrete change, supporting youth in channeling voice may seem hopelessly indirect. However, Butler (1997) argues that critical change occurs primarily through radical resignifications rather than through disruptions of overt power hierarchies. Clay's (2012) ethnography of youth activists similarly reports that their work today centers practices of figuring out who to be and how to get heard, in spite of the fact that much of the older generation does not understand the importance of this work.

I use the term *channeling voice(s)* to refer to the Bakhtinian sense that language is shot through with existing meanings (heteroglossia), so that meaning-making is more a process of selecting, arranging, and interpreting than it is one of hermetic manufacturing from raw materials. In moving away from a concept of voice linked to a presumed authentic self, I choose to talk about *channeling voices* rather than *finding* or *developing* voice to emphasize that every voice is dialogic, composed of and understood in relation to other voices.

Channeling also has helpful connotations in the domains of media and computer science. We have moved from a media environment with an enumerable collection of

dominant channels (e.g. NBC or CBS) to a fragmented multiplicity of blogs, Twitter threads, and social media feeds, each functioning as a channel and all competing for attention. These kinds of channels function like television broadcast channels in that they select and deliver content, establishing expected conventions and addressing themselves to presumed audiences. But their existence is more tenuous, depending only on a mutual agreement between sender and receiver. Social media channels behave much like the sense of *channel* in computer science: channels render signals as information by defining protocols by which the signal can be parsed, and a logic of addressability by which interlocutors can connect to one another.

The computer science sense of *channel* foregrounds Bakhtin's concern with addressability and genre. A computer can only send and receive messages on the Internet if it conforms to protocols like HTTP. Otherwise, the bits sent out will never reach their destinations or they will be unintelligible. In the analogous case of identity-as-interface, protocols of communication are defined by genre. (As noted above, I use *genre* to refer inclusively to Bakhtin's *speech genres*.) The possibilities of voice are constrained by recognized genres in the same way that the possibilities of identity authorship are constrained by subject positions. Who we can be and how we can communicate are thus *figured* in particular ways within a literacy place.

The metaphor comparing human sociality to computer networks only goes so far. *Channeling voice* is meant to have an ambiguity similar to *authoring identity*; we do not merely choose a voice from those available, but we also transform genres by proposing new configurations of voice. We invite recognition of new ways of interacting which may

or may not be taken up. For example, a talk at a computer science conference began with a land acknowledgement. This reframed the significance of rest of the talk, making some questions more urgent and others inappropriate. The land acknowledgement was an address to certain identities, inviting the audience to think of itself as positioned within historical processes of colonialism. I see the land acknowledgement as an example of channeling voice which challenged the presumed public of the conference (white, male, neutral, and intellectually detached) and invoked a counterpublic (Warner, 2002) which might be receptive to other voices and which might recognize other identities. How is it possible to be neutral while standing on occupied territory?

In contrast to computers (which are indifferent to the Internet), Butler (1997) argues that we need and desire social existence. "Subjection exploits the desire for existence, where existence is always conferred from elsewhere; it marks a primary vulnerability to the Other in order to be" (pp. 20-21). Holland et al. (1998) similarly argue that "the world must be answered" (p. 272). In authoring identities and channeling voice, we gain our social existence while at the same time making ourselves vulnerable. But this vulnerability, our universal dependence on the figuring power of figured worlds, is also the reason our identity authorship and channeling of voices can change our worlds.

Worlding

Identity authorship and channeling voice are strategies of incremental transformation. I have framed both as dialogic: as constructs which do not stand on their own, but which are defined and recognized in the context of existing subject positions and genres, while also seeking to transform them. I close this section by noting worlding as an alternative

conception of change. What if, instead of incremental transformation of subject positions and genres, it were possible to introduce an entirely new world, with new possibilities of being and acting, all at once? Some uses of the term worlding propose this as a viable, or even necessary form of change. The negative answer to a central question of postmodernity, "Can the subaltern speak?" expresses a fundamental skepticism of incremental change, that inferior and marginal subject positions are intrinsic to the figured worlds of dominant cultures (Spivak, 1988). The implication is that for change to be effective, it must be revolutionary.

The theoretical framework through which I approach the research in this dissertation does not provide an account of revolutionary change. I am skeptical of the possibility of a clean break from the past. Even when revolutionary change is proposed through worlding (e.g. manifestos or speculative fiction), that worlding will be encountered within the context of an extant literacy place, and dialogic questions about what it means in context and whether it is legible will come up. Worlding could also be conceived of as a mode of critical change different only in degree from identity authorship and channeling voices, a simultaneous reconfiguration of multiple subject positions and genres. It could be that a concerted effort would shift the paradigm of the literacy place even when each of the component actions would be blocked on its own. As a concrete example, I believe an effort to change a school's English/Language Arts curriculum so that it centered racial justice would be far more likely to succeed if there were simultaneous efforts among the faculty, students, and the community to legitimize identities and voices which were previously erased.

Interactive storytelling

The media which undergird a literacy place, serving as its semiotic infrastructure, shape literacy practice and afford specific possibilities for identity authorship and channeling voice. My design-based research with interactive storytelling was motivated by a recognition of these possibilities. Interactive storytelling is a generalization of interactive fiction, a medium authored with text and code to create single-player text-based games and stories. Interactive storytelling had a widespread following from the late 1980's through the 1990's, bounded chronologically by the emergence of personal computers and early access to the Internet and its displacement by graphical games made possible by improvements in processors and displays (Labrande, 2011). Over the last several decades, interactive storytelling has retained a small but active community, often articulating feminist and queer critical responses to the ideologies dominant in the discourses of mainstream video games (Anthropy, 2012).

There have been numerous educational studies of interactive storytelling, focusing on its potential to support participation in communities of practice (Bruckman, 1997; Kafai & Fields, 2013), incorporating computer science into existing literacy practices (Burke & Kafai, 2010), as a narrative form in its own right (Montfort, 2005), to support critical computational literacies (Lee & Garcia, 2014), and specifically to support dialogism in digital media (Nelson & Hull, 2008; Yardi, 2008). Nelson & Hull (2008) draw on Bakhtin's concept of the *chronotope*, "the intrinsic connectedness of temporal and spatial relationships that are artistically expressed in literature" (p. 84) to argue that there are different representational possibilities in different media. Murray (2017), among others, considers the nature of storytelling in cyberspace. (I return to the relationship

between media and its representational, rhetorical, and critical affordances in more detail in Chapter 4.)

Interactive storytelling has particular potency for storytelling in youths' digital worlds, where genres are dynamic but not dialogic. Instead of gaining control over social media as we internalize it (as in Vygotsky's theories), we are colonized by it. Social media feels close and intimate, but it is a sinister sort of intimacy without reciprocity. Bakhtin discusses how laughter brings things close to us and gives us power over them (p. 23). We can laugh at the content of social media, but lack tools to parody the genre itself. Partly, this is because of technical limitations placed on us as users: tweets can only appear in certain contexts, and this is under the control of Twitter.

A medium with dialogic properties would be able to inject itself into other genres, so that they "become dialogized, permeated with laughter, irony, humor, elements of self-parody and finally… an indeterminacy, a certain semantic openendedness, a living contact with unfinished, still-evolving contemporary reality (the openended present)." (p. 7) The novel can do this for the genres of print literacy: "Take, for example, the parodic sonnets with which Don Quixote begins. Although they are impeccably structured as sonnets, we could never possibly assign them to the sonnet genre. In Don Quixote they appear as part of a novel–but even the isolated parodic sonnet (outside the novel) could not be classified generically as a sonnet. In a parodied sonnet, the sonnet form is not a genre at all; that is, it is not the form of a whole but is rather the object of representation." (p. 51) We have no forms for equivalent parody of social media, and I hope interactive storytelling can support "parodic stylization of canonized genres" in the

domain of social media (p. 4). I see the computational qualities of Unfold Studio, combined with its ability to represent the forms of social media (the tweet, the sms message, the snap, the Instagram post) as an important possible catalyst for channeling voices. This goal aligns the two axes of Figure 2.1, putting cognitive and situated literacy practices in critical context by helping participants to become aware of the relationship between practice and its infrastructural media.

Research questions

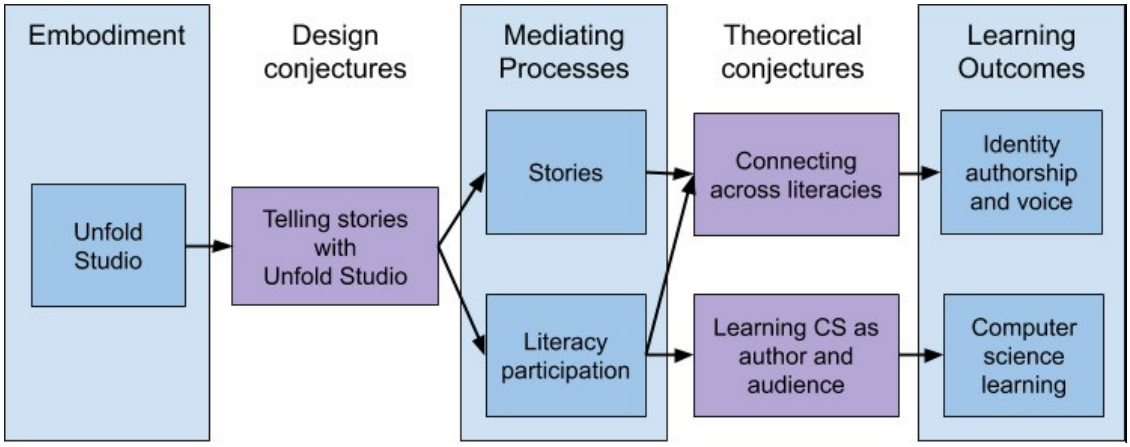

Figure 2.2: Conjecture mapping showing locations of research questions within conjectured patterns of change

This literature review moved from broad to narrow: first framing ((critical) computational) literacies, then discussing identity authorship and channeling voice as hoped-for outcomes, and finally explaining why interactive storytelling might be effective in producing these outcomes. Figure 2.2 shows a conjecture map (Sandoval, 2014) which surfaces both design conjectures linking the embodied design of Unfold Studio (Proctor & Blikstein, 2019) to mediating critical computational literacy processes, and theoretical conjectures linking these to the development of computational thinking

skills, identity authorship, and voice. These conjectures are the research questions which become the foci of chapters 4, 5, and 6.

RQ1: How do participants use textual and computational affordances of interactive storytelling to author texts with critical possibilities?

This chapter analyzes the relationship between literacy practices and the infrastructural technologies which support them. I use the framework developed in Proctor & Blikstein (2019) to trace how the perceived affordances of a computational medium (Unfold Studio and the Ink language) shape the rhetorical practices for which it is used; how these practices shape the identities and voices which are thereby enacted; and how these identities and voices open possibilities for critical understanding and activism. Because the perceived affordances of a medium shape literacy practices, I hypothesize that understanding the infrastructural technology (through computational thinking) could support critical understanding and production.

RQ2: How do participants connect across literacies through identity authorship and channeling voices?

This chapter analyzes how a classroom literacy place can play a productive role in participants' broader digital media ecosystems, specifically how participants connect their existing literacies to the classroom literacy place through identity authorship and channeling voices. Connecting across literacies allows participants to transform subject positions and genres in the classroom literacy place to make room for desired identities and voices, while bringing disciplinary sense-making practices (which I also understand as genres) from the classroom into their other literacies. This chapter pays particular

attention to how common affordances of infrastructural media across literacies support mobility across literacies.

RQ3: Does participation in an interactive storytelling literacy place support computer science learning?

This chapter shows that participation in reading and writing interactive stories on Unfold Studio was associated with better performance on a summative assessment of computer science learning, and that this effect was mediated by the amount of student practice with computational concepts while writing their stories. Based on this analysis, the chapter develops an argument for a literacy-based approach to K12 computer science. Additionally, this chapter develops measures of two forms of participation, authorship and audience, which may be valuable in future research framing learning in sociocultural terms.

Methods

This dissertation is a mixed-methods study exploring three related questions (one design conjecture and two theoretical conjectures) about critical computational literacies. In the context of a ten-week classroom study, a number of data sources and analyses were used to answer the research questions. This work is the culmination of an iterative design-based research process through which I designed and developed a web application for interactive storytelling called Unfold Studio (Proctor & Blikstein, 2019). This chapter discusses the dissertation's methods broadly, introducing the site, participants, tools, and curriculum involved in the study, and then tracing the research process used in each of the three following chapters. Each of these chapters also contains its own methods section discussing finer-grained details specific to that chapter's approach.

Context

Study site and participants

This research was set at "Harrison Middle School" in "Riverton," a small city in the American midwest, during April and May 2019. I collaborated with "Andrew," a sixth-grade computer science teacher on a ten-week curriculum unit using a literacy-based approach to teaching introductory computer science. I met Andrew when he attended a workshop I gave at the 2018 Computer Science Teachers Association conference. Over the nine months between that workshop and the present study, he and I collaborated on five iterations of a two-week unit on interactive storytelling, through which we developed a strong working relationship and an array of new pedagogical strategies. While the study

site was selected because of this ongoing collaboration, its selection also helped address inequitable representation in my research, as well as the field of computer science education research. Most US research in this field takes place in a handful of states (See Figure 3). Harrison Middle School is a semi-rural midwestern Title I school, largely disconnected from the coastal ecosystems of computer science learning and opportunity, as well as computer science education research.

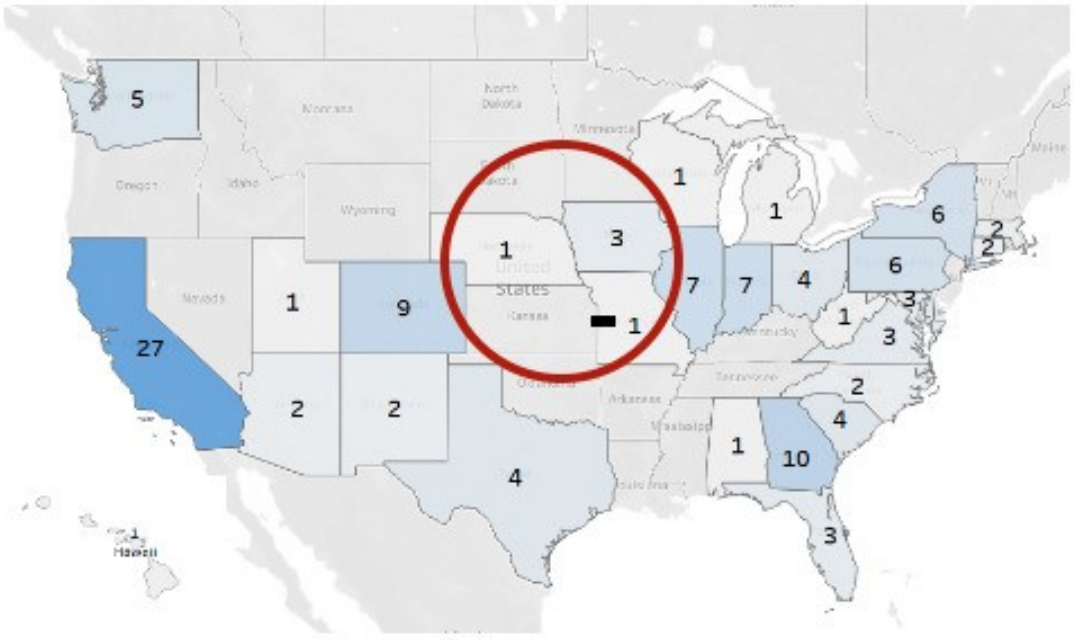

Figure 3.1: Study site, overlaid on a map showing number of computer science education research studies conducted per US state (Upadhyaya, McGill, & Decker, 2020)

Riverton is located along a bend in a large river, whose fertile soil supported dense indigenous populations of the Woodlands and the Great Plains cultures for thousands of years. Following their forced removal in the mid-nineteenth century, Riverton was established as a county seat at the confluence of several railroad lines, and became a regional hub for agriculture and livestock. Riverton experienced substantial

immigration from Eastern Europe during the mid and late Nineteenth Century, and had a thriving economy dominated by milling and livestock processing industries. Riverton was a stop on the underground railroad and had an active abolitionist movement. Riverton's second major wave of newcomers came during the Great Migration, when Black citizens escaping oppression in the American South found Chicago unwelcoming and continued west along the rail lines. I learned this history through visits to several museums and cultural centers in Riverton. On my long drives in from the nearest major airport, I listened to Isabelle Wilkerson's *The Warmth of Other Suns* (2011) and imagined what the parents, grandparents, and ancestors of Riverton's current residents must have felt as they converged on their new home.

More recently, Riverton experienced the tragically-familiar pattern of white flight and urban disinvestment following school desegregation from the 1950's to the 1980's. This, combined with a loss of well-paying agricultural manufacturing jobs and car-centric development (suburbs and highway overpasses through the city), led to degradation of the urban fabric. Today, the major employers are grain mills, a military contractor, an insurance company, and a hospital system focused on long-term and hospice care, as well as many minimum-wage service jobs. While there are affluent suburbs with lush streets and country clubs, the neighborhood around Harrison Middle School is not prosperous. Harrison is located on an arterial road where the grid of city blocks shifts its orientation, and which was for decades the boundary of the Black part of the city, enforced by redlining and social codes. Because of school zoning, Harrison concentrates Riverton's least well-off citizens.

Figure 3.2: Harrison Middle School

Harrison Middle School's students are reported as 57% white, 25% black, and 10% two or more races. 55% of students are eligible for free or reduced lunch and the school is in the tenth percentile for state test results. Through students' writing, classroom discussions, and survey responses, I learned that many of their families contend with limited economic opportunity and resulting instability. Several of the students who live in the neighborhoods surrounding the school talked about spending after-school time in marginal places like abandoned houses, railroad right-of-ways, and forested river banks. The recently-renovated public library was an important third place for these students. While students had a range of opinions about how safe the school felt, caring adult attention was evident. The school has embraced a restorative justice model of conflict resolution, and I saw several signs announcing that any student who needed a place to do laundry should contact a teacher for free and confidential access.

Of 149 sixth-grade students across Andrew's six sections, 50 participated in this research. Very few had prior exposure to computer science. Students had computer science for an 80-minute block period two or three times a week, for a total of 27 hours of classroom time over the fourth quarter of the school year.

In addition to Andrew, the sixth-grade computer science teacher, two other adults played central roles in the research. "Caroline" is a computer science specialist employed by the regional education agency (between the level of school district and the state), which is leading an initiative to support K-12 computer science. Andrew unexpectedly resigned about halfway through the unit and was replaced by "Ben," a social studies teacher and baseball coach who finished out the school year as a long-term substitute. This transition was disruptive to the course and to the study, but both Ben and the school leadership were enthusiastic about continuing, as it provided some curricular continuity. Caroline initially joined the classroom as an observer, but began coming more frequently after the transition, as a way to support Ben's growth as a computer science teacher and to work with students directly.

This extra adult attention was particularly valuable for students who needed support with reading and writing. Caroline frequently sat with individuals or small groups, supporting them in writing down their ideas, revising, and sharing and discussing their writing. Caroline's presence was also extremely valuable for my research, as our pre-class planning and post-class reflection (in part intended as a way of supporting Ben's growth in computer science pedagogy) created a context for thinking with another

experienced practitioner. Caroline and I became friends, and have taught several professional development workshops based on this work.

As a teacher and as a researcher, I tried to positioned myself as an interested but nonjudgmental outsider. While I established warm connections with numerous individuals during class discussions and through interactions on Unfold Studio (leaving comments on stories; helping students debug and revise), other students made clear that they saw me as an untrustworthy outsider, sometimes writing "sorry, that's too personal" or "not going to share that" on end-of-class exit ticket questions asking what stories they were considering writing about, or how well they felt they had learned a concept. While these questions did ask students to share parts of their identities as learners, they seemed to me to be part of standard pedagogical practice and I was surprised at their response. Andrew and Caroline both told me at different times that they felt like outsiders to the school, Andrew because he lived outside the city and was separated by religion and social class, and Caroline because she represented the threatening authority of the state education administration.

My distance from the school's culture intersected other dynamics such as race. I was troubled by my perception that the school did not maintain high academic or behavioral expectations for its Black students. Within this world, some Black students authored identities for themselves as studious high achievers, but others were figured in terms of the discourse of discipline. I noted a reciprocal distrust of the mostly-white faculty which extended to me. When I expressed surprise that one Black student apparently came and went from the classroom as he pleased, he told me it was none of

my business. At the same time, my distance from the school culture made it possible to open some conversational spaces. The unit's essential question was "How do we build our worlds," an exploration of how the various worlds in which we each live afford different subject positions for possible selves. Through a series of class discussions, we extended this exploration from video games and interactive stories to the city of Riverton and Harrison Middle School. We had several poignant conversations in which students shared their perceptions of how they were treated differently at school because of their race or language, and the strategies they used to accommodate or respond to these stereotypes. These discussions, along with interactive stories students wrote exploring these ideas, represented some measure of the critical possibilities which were a primary goal of this study.

Some students' distrust of me affected my intended research. Andrew and I planned a thorough discussion of what it means to participate in research, participants' rights, and the proposed research procedures. We scheduled additional time without me present for Andrew and his students to talk and develop additional questions, and then a follow-up conversation where students could ask me questions or have Andrew ask them. A number of students were concerned about my proposal to video record class sessions. I affirmed their concerns and explained that while I am also concerned about digital surveillance generally, I feel the privacy risks of being video recoded in a study supervised by an IRB are smaller than everyday cell phone use or trips to almost any grocery store or fast food restaurant. We agreed that I would only record one corner of the classroom, that I would make sure anyone who was not participating in research

would not sit in that corner, and that I would delete all the videos after analyzing them in my research. (These were already the conditions I had proposed in my IRB). Nevertheless, several students began to vocally protest the presence of video cameras and would occasionally unplug them or cover them with tissues. After a follow-up discussion about video recording, a handful of students still felt strongly that they did not want video recording to take place in their classroom, so I decided the ethical course of action was to stop recording. I modified my research plan accordingly.

This research was conducted under the supervision of Stanford University's IRB, with the permission of the Riverton school district and the principal of Harrison Middle School. All data was collected from participants who consented to participate in the study. Participants who were minors also had the consent of their parents or guardians. All participant names have been changed to pseudonyms selected by the participants, or selected by me when participants did not select one. Place names have similarly been changed.

Unfold Studio and interactive storytelling curriculum

The curriculum unit was designed according to Wiggins & McTighe's (2005) Understanding by Design, and will be centered around the essential questions, "Who can we be?" and "How do we build our worlds?" These questions are aimed directly at the central constructs of this research: the authorship of identity in social context. The primary pedagogical approach was that of writer's workshop, with students engaged in reading and writing interactive stories (though we also read other kinds of texts). This curriculum was initially developed in a prior pilot study (Proctor & Blikstein, 2019). We

used an introductory sequence of story prompts, supported by mini-lessons focused on writerly craft, programming ideas, and other topics that have proven important in previous iterations, such as teaching students how to read and debug code.

Unfold Studio was developed primarily as a platform to support interactive storytelling and related pedagogy. However I was also intentional in developing it as a research instrument. Much of the data collection, and a substantial portion of the initial analysis, took place on Unfold Studio. This section presents a brief technical overview of Unfold Studio. This section's goal is to explain what the system collects and how it is processed to a reader not necessarily well-versed in web technologies. The goal is to ground the subsequent discussion of data sources, not to document the software's inner workings.

Unfold Studio is a web application running on several cloud-based servers. It is written mostly in Python, using the Django (Django Software Foundation, 2020) web framework. Generally, all users interact with the same instance of the program ("Site" in Figure 3.3 below), meaning they are all part of the same world and can interact with each other and each other's stories. That said, Unfold Studio supports multiple sites, so that in the future a school or writing club which wanted more privacy could have a world accessible only to members.

Users interact with Unfold Studio by making requests through their web browser and then receiving a response. A request might include logging in to the site, browsing the story index, viewing a user's story, creating or editing a story, or following another user. Each of these requests can be interpreted as an action undertaken by the user, and

each is recorded in a log. During the study period, Unfold Studio recorded over half a million user events.

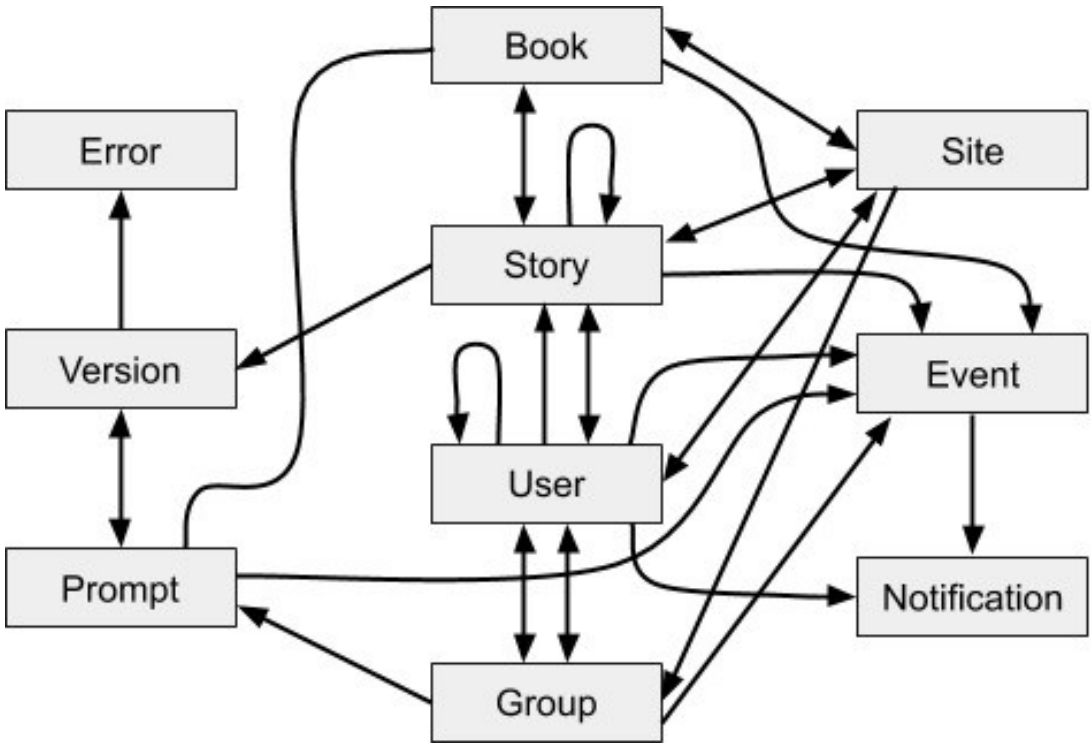

Figure 3.3: Simplified database schema showing relationships between models in Unfold Studio

Figure 3.3 shows a simplified database schema for Unfold Studio. Anything that exists or has ever existed on Unfold Studio is stored in its database, making it a primary data source for this dissertation. Each rectangle represents a table in the database. Arrows indicate relations between tables. Arrows with heads indicate that there may be many relations in that direction. For example, each story may have many versions, and each version may have many errors. Double-headed arrows indicate a many-to-many relationship. For example, a group may have many users and a user may belong to many groups. Self-loops represent relationships between instances of the same model, such as

users following each other or child/parent relationships between forked stories. Finally, multiple arrows between the same models represent distinct relationships. For example, a story has a single author and potentially many users who love it. Users can be members of groups or they can be group leaders.

Most of the processing that takes place when users interact with Unfold Studio takes place on the server, not in the user's web browser. This is called server-side rendering. The major exception to this is that stories are played using a javascript runtime environment. When playing a story on Unfold Studio, the story's dynamic content is generated in the web browser, without a trip back to the server. Similarly, if a story encounters a runtime error such as infinite recursion, the error is generated in the web browser's environment, not the server's. (While users' choices during a story playthrough occur within the browser's runtime environment, they are recorded and sent back to the server. In the future, I am considering showing story authors which paths readers tend to follow through their stories.)

Although stories are played in the browser runtime environment, they are compiled on the server. Unfold Studio's stories are written in a programming language called Ink (see below) which needs to be compiled before it can be run. The decision to compile stories on the server rather than in the browser was forced by the lack of a javascript implementation of the Ink compiler and my disinclination to write one. However, it also enables some features and data collection. For example, users can include scenes or characters from other stories in stories they are writing. This is only possible on the server, where authorization logic can be applied to make sure the author

has permission to access included stories. Furthermore, every version of a story is logged in the database, and when stories contain errors, these are classified and logged as well.

Following the tradition of *The Sciences of the Artificial* (Simon, 1969), this dissertation is largely concerned with artificial data, which is to say the data is evidence of interaction with a designed artifact, not a natural phenomenon. The stories analyzed in Chapters 4, 5, and 6 were retrieved from the Story table of the database, sometimes using the Version table to study how the story developed. The user events analyzed in chapters 5 and 6 were extracted from Unfold Studio's logs.

Ink

Stories on Unfold Studio are written in a programming language called Ink (2019), which was designed to feel as much like writing prose as possible. The narrative is divided into knots, containing anywhere from a phrase to multiple paragraphs of prose. Typically, a knot ends with several options to be presented to the player, where each choice causes the storyto divert to another knot. For example, Figure 3.4 shows the beginning of a playthrough of "High School Kickback," the student-authored story analyzed in Proctor & Garcia (2020). The unfolding story is on the right; its source code (always available to players) is on the left.

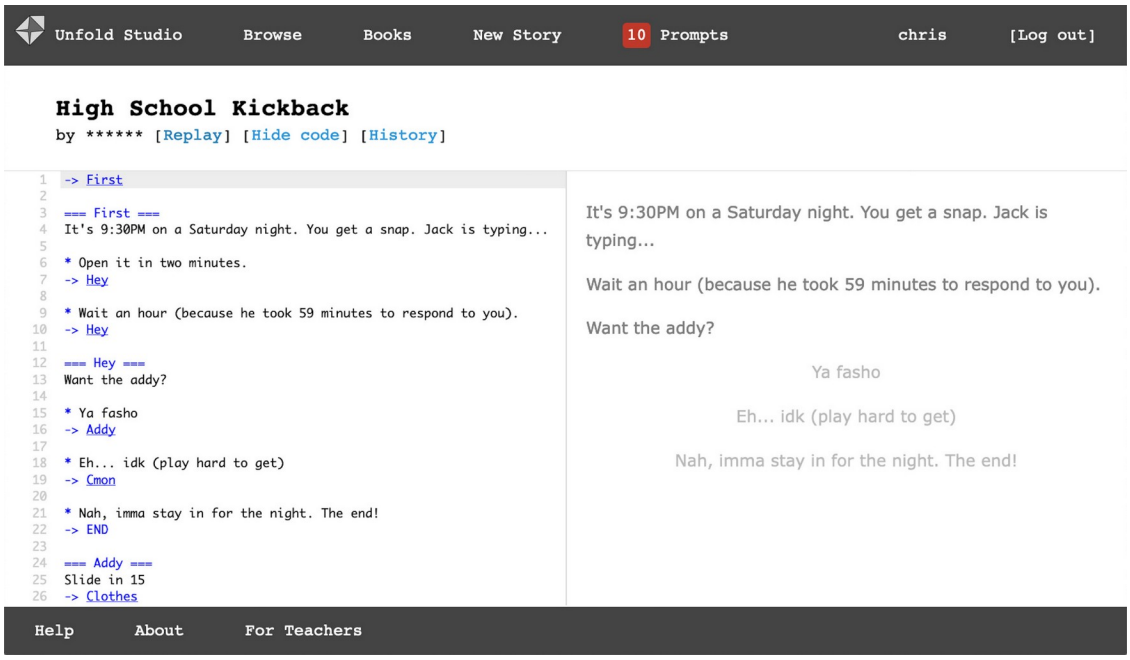

Figure 3.4: Screenshot of Unfold Studio

The first ten lines of code in Figure 3.4 illustrate the basics of Ink syntax. The first line (`->First`) is a divert, instructing the story to continue at a knot called "First." This knot is defined starting on line 3 (`=== First ===`). When the story reaches "First," the player sees the text, "It's 9:30PM on a Saturday night. You get a snap [Snapchat message]. Jack is typing…", and is then presented with two options. If the player clicks "Open it in two minutes," the story will divert to "Hey" (which is defined on line 12). If the player instead decides to wait an hour, the story also diverts to "Hey." The player would perceive a choice, but the story proceeds the same way regardless of what she chooses.

Ink was initially developed by the game studio Inkle as an internal scripting language allowing collaboration between software developers and writers. Ink became prominent with the 2014 release of *80 Days* (Studios, 2014), an interactive storytelling

game which won Time Magazine's 2014 Game of the Year award and the Independent Games Festival's 2015 award for Excellence in Narrative. Ink's first public release was on March 3, 2016, and I immediately began exploring its potential as a pedagogical tool. The earliest commits to the project which became Unfold Studio were made during a middle-school interactive storytelling workshop at the beginning of April 2016.

Ink is an unconventional programming language in that it is organized around the structure of prose. The fundamental unit of content is the knot, which can range from a few words to many paragraphs. Knots are generally connected to one another through diverts, which function redirect control flow similar to a Fortran GOTO statement. Using tunnels, it is also possible to divert to another knot while pushing the current knot onto a call stack and returning to it (this includes recursion). Finally, knots may be parameterized with arguments and may have return values, enabling their use as functions.

Within knots, content toggles between literal output to be displayed to the player and a program execution environment where variables can be assigned and checked, control flow statements such as conditionals can be executed, and dynamic values can be computed. This functions much the same way as HTML webpages are created in PHP, toggling between a literal output mode and a program execution environment. The end result is a programming interface which elegantly supports incremental inclusion of code and computational constructs, starting from none at all. A sequence of prose paragraphs–regular writing–is also a valid program in Ink.

This is a bold interface for an introductory programming language in that it makes substantial tradeoffs in favor of connecting with existing literacies. Ink is probably not as well-suited as a powerful representational medium for computer science concepts such as data structures, algorithms, types, and abstractions, as languages such as Logo, Lisp, Snap!, or even mainstream languages like Python or Java. At the same time, Ink remains computationally complete (any program that can be written in any programming language can also be written in Ink) and foregrounds interaction with code in ways that other interfaces for nonlinear writing such as Twine do not. My research so far has focused more on questions of identity, culture, and practice than on perceptual and epistemological questions in the domain of human-computer interaction. (Until I showed that Ink can be powerful as a literacy medium, I did not see the justification for more specific research on Ink's interface as a programming language.) However, future research will explore this direction.

Methods Overview

This section provides a high-level summary of the methods used across all three research questions. Hopefully, this section contextualizes the methods section presented in each of the three following chapters, and addresses methodological issues relevant to all of them. My discussion of methods follows the pattern laid out in Shaffer's (2017) *Quantitative Ethnography,* which provides common language for addressing methodological issues in qualitative and quantitative approaches. I borrow this terminology in the column labels shown in Figure 3.5. The methods section of each following chapter traces the methodological process specifically relvant to that chapter's research questions.

Figure 3.5 may appear overwhelmingly complex at first, so the following paragraphs will introduce the methods column by column, describing at a high level how the dissertation moves from phenomena to answering research questions.

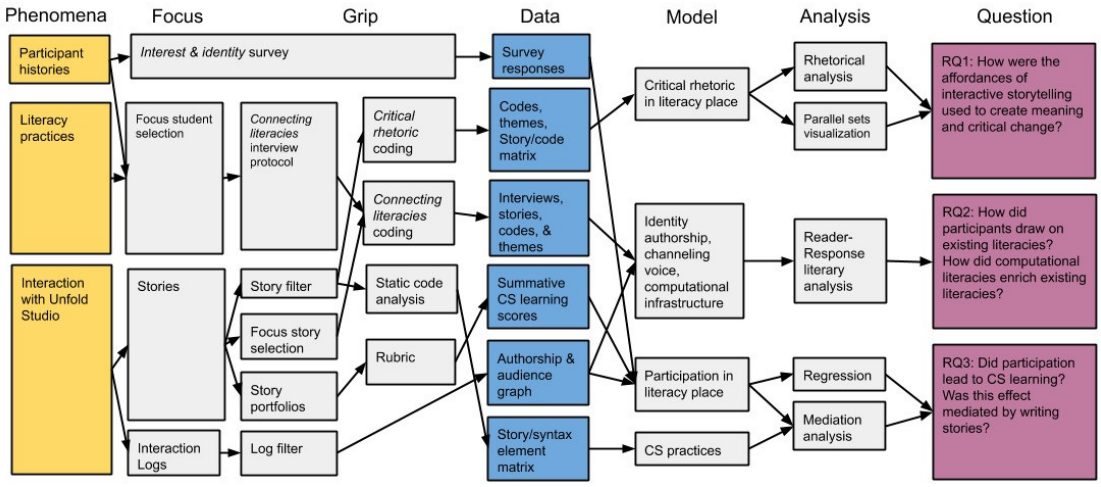

Figure 3.5: Overview of methods

Phenomena

Phenomena are the ineffable processes I want to study. Phenomena cannot be studied directly, in part because the phenomena I am interested in are at least partly subjective (e.g. identity, voice, and literacy participation). But even comprehensions of phenomena unrelated to someone else's subjectivity will reflect the instrument through which it was comprehended as much as what was measured. This applies to physical technologies such as Unfold Studio's database and logging system, which record data in certain ways, as well as instruments like conceptual frameworks, which influence what is perceived and recorded. Therefore, attention to *focus* and *grip* are required so that I have a clear understanding of the instruments through which I approach phenomena.

Focus & Grip

Focus is the way in which I direct and narrow my attention. For field notes, focus means where I chose to go, when I chose to take notes, and which aspects of activity I decided to record. Focus includes inclusion criteria for which stories are considered part of the corpus and selection criteria for which students and stories are selected for deeper study.

Grip refers to the interpretive processes I use to formalize and record data about phenomena. This includes taking field notes to transform perceptions into records, and then qualitative coding to transform field notes and interview transcripts into codes and coded texts. Grip includes procedures for feature extraction such as scoring rubrics and static code analysis, where I count instances of certain syntactic constructs. The boundary between focus and grip is indistinct.

Several strategies were used to gain focus and grip on the phenomena. I took field notes during class sessions when I could, and went for long walks every day after school, dictating to myself the notes I could not jot down during class. I also made intentional traverses through the city–along the river, across socioeconomic gradients, in a loop around downtown. I visited the places my students wrote about, and took field notes on these experiences as well, primarily thinking about how my students experienced the space of the city.

Unfold Studio was both a primary phenomenon (a participant in literacy interactions) as well as a research instrument providing focus and grip by modeling stories and interactions in particular ways in its logs and database. I developed criteria for which stories to include in the corpus, and filtered the user interaction log to only

consider certain interactions with these stories. I used interview protocols aligned with their respective research questions to learn about the literacy practices of my focus students and the pedagogy of the participating teachers. Then I processed these texts (field notes, students' stories, interview transcripts) using three separate qualitative coding processes aligned with three research questions. In each case, the top-level codes were provided by a theoretical framework and the lower-level codes, which developed into themes, emerged as grounded theory.

I also extracted several quantitative features. For the unit's summative assessment, students submitted a portfolio of what they considered their best stories, one focusing on technical skills and one on storytelling. The technical skills stories were assessed using a rubric aligned with the unit's computer science learning goals. User interaction logs were compiled into a graph of interactions between users and stories, from which authorship and audience scores (out-degree and in-degree of user nodes, respectively) were computed. And a simple form of static code analysis was applied to students' stories, counting the appearances of certain syntactic features. Finally, I used an existing survey (Friend, 2016) to assess students' prior interest and experience with computer science.

Data

Data are concrete records produced by the previous steps. In some cases the model precedes the data and dictates its form, such as when a regression analysis depends on certain input variables In other cases, the model provides a general shape, but some form emerges from the data, such as when a theoretical framework provides high-level

categories for qualitative coding, but themes within these categories emerge through coding.

The following is a summary of the data used across all three research questions. There are three sets of coded texts including student-authored stories, interviews, and field notes, with the codebooks aligned with research questions 1, 2, and 4. The first research question uses code counts (with the document as the unit of analysis) to make claims about the frequency of codes. The other two sets of codes and texts are used to surface themes, but are not used quantitatively. The remaining quantitative data are used primarily for the third research question: summative scores of computer science learning, students' authorship and audience scores, extracted from the social network graph of interactions between users and stories, per-story counts of syntactic constructs, and survey responses.

Model

The *model* is an abstract representation of the phenomena of interest, which represents the phenomena in a way that makes them tractable for analysis. Quantitative models can be used to automatically answer questions, whereas qualitative models such as conceptual frameworks or models of process guide manual analysis.

The models used in the dissertation represent different processes of a literacy place, the conceptual framework developed in Chapter 2. The first research question uses a model of critical rhetoric within the literacy place, or the ways authors made use of Unfold Studio's interactive storytelling affordances to shape meanings addressed to particular audiences, and how this work created possibilities for critical change. The

second research question focuses on critical change at an individual level through identity authorship and channeling voices, with particular attention to how computational media supported connection across literacies. The third research question considers the relationship between participation in literacy practices (as an author and as audience) and computer science learning. And the final research question focuses on the pedagogy which supported connection across literacies, using a transliteracies framework (Smith, Stornaiuolo, & Phillips, 2018; Stornaiuolo, Smith, & Phillips, 2017).

Analysis

Analysis describes the ways I use the model, parametrized with data, to address the research question. The first two research questions rely on two forms of literary analysis (rhetorical analysis and reader-response analysis). The first uses the four-phase model of critical rhetoric developed in prior work (Proctor & Blikstein, 2019) to describe broadly the study participants' meaning-making. Here, the codes are organized into four phases, and I analyze relationships between the phases, such as how offering the player choices or withholding them was used to manipulate the player's perception of agency or how the literary technique of point of view was used in identity authorship. I use a strategy method called parallel sets (Kosara, Bendix, & Hauser, 2006) to visualize the distributions of codes across phases, and I analyze excerpts from stories to illustrate how they work.

In contrast, the second research question approaches stories as containing the potential for players to produce unique readings while playing them. This framing allows me to analyze several case studies of authors drawing on their existing literacies to write

stories whose players will be able to participate in those worlds, which may not already be accessible within the classroom literacy space. For example, one focus student is an active participant in an online community interested in queer horror games and podcasts. How might a story written and shared in the classroom literacy place allow its players to participate in the genre of queer horror, and thereby recognize new subject positions and genres? For each case study student, I conduct a reader-response analysis of one story.

The third research question's analytical strategy is standard linear regression estimating the relationship between each of two different forms of participation in a literacy place and a summative measure of computer science learning. I complicate this somewhat in a sub-question which considers whether this effect is mediated by practice writing stories using syntactic constructs realted to computer science ideas.

Question

Finally, *question* names the research question toward which the preceding steps have been aimed. The three research questions motivating this dissertation were discussed in detail at the end of Chapter 2.

Methodological tools

QC: Qualitative Coding

Several of my research questions rely heavily on qualitative coding to annotate qualities of texts such as student writing, field notes, and interview transcripts. I synthesize this coding thematically and analyze its distribution to develop arguments about broad-scale patterns and what they mean. There are several existing tools for doing this work such as Nvivo and Dedoose, however I found using them unsatisfying. Their interfaces do not

support They were designed for non-programmers. They present graphical user interfaces, are proprietary, and do not expose the data in well-structured ways. I found that these interface limitations prevented me from thinking with powerful concepts from computer science during the process of qualitative coding, such as trees, sorting, filtering, version control, and integration into larger task pipelines.

I developed a software package called Qualitative Coding, or qc (Proctor, 2020), to take advantage of these opportunities. I used qc as a primary coding tool in a prior paper presented at SIGCSE paper on how K-12 schools define and design computer science courses(Proctor et al., 2019). Inspired by NetLogo (Wilensky, 1999), Boxer (diSessa & Abelson, 1986), the GoGo Board (Sipitakiat et al., 2004), Shaffer's (2017) emphasis on building tools, and especially the and the open-source scientific computing ecosystem in R and Python, building computational infrastructure which supports richer research practices feels like an important part of the broader research project.

Managing the codebase

Finally, my prior experience with logistically- and computationally-intensive research projects has convinced me that it is essential to keep them organized in multiple ways. Data and results need to be kept organized; analysis (including the generation of tables and charts) needs to be tracked and fully-reproducible; changes need to be tracked and progress needs to be managed with short- and long-term planning. In short, research needs to be treated like software development.

Therefore, I have organized my dissertation work like software. The entire project is kept in two git repositories: one holds (potentially personally-identifiable) raw data,

and the other holds anonymized data, analytical code, writing, code to generate images, and commands to build, export, and upload the final product. The top-level interface is a series of commands with options implemented using Python's Invoke package (Forcier, 2020). The end result is that I can clean up a mistake in the data, make some tweaks to an analysis script, update the parameters for generating a figure, or edit a chapter's text, and then re-run the entire build system from raw data to exported document with a single command. In the future, I hope this helps me to produce reproduce reproducible research efficiently by sharing and reusing tools and analytical code.

Human in the loop This tooling enacts a central theme of the learning sciences, that cognition is situated and distributed in our tools. The tools we use go beyond augmenting human capability (Engelbart (1962)); they shape our practice and even our embodied sense of self. This dissertation would not have been possible without computers and computer science. However, I am also wary of relying too heavily on infrastructure we do not fully understand. Writing some of the tools upon which this dissertation relies has provided me an opportunity to reflect deeply on the processes I am using to collect and analyze data, and has helped me to avoid making arbitrary decisions grounded in how the tool was built.

Trajectories of story development and audience engagement

I wanted to be able to study the developmental trajectories of stories–how students developed them. To do this, I pulled the edit history for each of the focus stories, and developed an "edit viewer" which allowed me to scroll through each savepoint in the story. Each focus student discussed the process of writing their stories, and this edit

viewer allowed me to see how they played out. Furthermore, I wanted to understand the social histories of the focus stories. I wanted to know what else students were reading as they developed the story, and how other students interacted with the stories. To do this, I filtered the Unfold Studio application log and developed tools which allowed me to view all interactions related to the focus student and the focus story. The slider bar shown below shows how the social history viewer allows the researcher to move back and forth through time.

Common interactive techniques include providing or denying agency to the player, allowing omnipotent control of the world (for example, allowing the player to choose the reactions of others or whether it rains), and inserting parenthetical remarks on the player's choices. Immersive techniques include allowing the player to construct an in-world identity and structuring choices so that the player becomes morally implicated in the story's events or is presumed to have given consent to events taking place in the story.

RQ1: Telling stories with Unfold Studio

Introduction

This chapter explores the ways in which a technological infrastructure of literacy can support the emergence of critical computational literacy practices. Unfold Studio is a web application which functions as a literacy place for interactive storytelling, allowing users to read and write interactive stories and to interact with one another via common social media affordances. Users can read and write interactive stories which are at once literary texts and computer programs. This chapter asks open-ended questions which could help advance the design of Unfold Studio: Which of the platform's affordances did authors use? How did they make use of the affordances in their stories? What kinds of stories did they write, and what did they talk about? How did writing interactive stories and reading peers' stories open new possibilities for identity authorship and channeling voice?

One theoretical motivation for these questions is that they provide concrete examples of youth enacting a literacy place. Studying these examples can help refine the concept of a literacy place, especially the role that interacting with media infrastructure plays in supporting identity authorship and channeling voice. Analyzing the relationship between infrastructure and these critical practices could help give a clearer account of youth critical computational literacy practices in their digital lives.

Another goal of this chapter is to illustrate how K12 computer science might be reframed in terms of critical literacy. A literacy-based approach to computer science would still value the skills and knowledge required for effective programming,

debugging, and reasoning about computational problems, but these goals would not be viewed as ends in and of themselves or as progress toward a particular definition of computer science given in advance. If we want to support and assess students' development as computer scientists from a literacy perspective, where the terms of quality are themselves normative and community-defined, we need a way of understanding students' work in terms of the audience for which they were produced. This stance is grounded in existing literary criticism, as well as criticism of music, film, and other creative expression.

In order to evaluate a creative work, it is necessary to ground the criticism in a genre: (often implicit and unstable) expectations about the work and criteria for excellence. One primary attraction of this stance is that it presumes agency on the part of individual youth and communities. Rather than starting from external standards (e.g. those adopted at a state or national level) and teaching toward assessments aligned with those standards, I propose to support and value homegrown communities of computational literacy in developing their own idiosyncratic taste in what constitutes exciting, high-quality work.

Is this wise? One might be concerned about supporting the emergence of a community of practice irrelevant to the demands of future coursework or the workplace, which perpetuates misconceptions or ineffective practices. However, I am motivated by the many examples of such communities of practice I have seen in my teaching and work with schools: student journalists, literary and artistic clubs, robotics clubs, makerspaces, and politically-engaged student government. Such communities not only produce

distinctive forms of literacy which are well-adapted to the broader learning ecologies in which they are situated, but they also tend to make more effective use of local conditions to offer ways in (learning opportunities) for beginners than standardized institutional models. They also tend to be keenly aware of their relationship to dominant professional practices.

That said, I do not want to claim too strongly that participation in emergent literacies is a good way to learn standard computer science. The third research question, analyzed in Chapter 6, is an empirical examination of how participants' literacy participation helped them to grow as computer scientists. In the spirit of preparation for future learning (Bransford & Schwartz, 1999), I would design a curricular sequence which initially prioritized participation and placemaking, so that later computer science courses could dive more deeply into specialized topics in a situated way. (This is precisely the approach we are currently taking in designing the computer science program at a school in Hong Kong (Proctor, et al., in preparation).)

Toward these goals, the first research question considers how the textual and computational affordances of interactive storytelling (as implemented using Ink on Unfold Studio) were used to author texts with critical possibilities. I view interactive storytelling practices as an extension of regular fiction or creative nonfiction writing (together referred to as literary writing) within a literacy place. The analysis here is extended in two ways. First, the writing medium is also a programming language, so the standard literary elements are extended to include computational elements (more on this in the Background section below). Second, I can do this analysis at high granularity and

broad scale. Because Unfold Studio collected every story in a format suitable for computer-assisted analysis, I can make some specific claims about all the participants across the ten-week unit. This is the approach I take in this chapter. Then, in Chapter 5, I zoom in with case studies applying literary analysis to stories written by several focus students.

Background

Chapter 2 proposed a structure for critical computational literacy. Figure 2.1 represents three scopes of literacy practice as concentric circles above a grid which represents infrastructure. I argued for two important axes: one axis is radial in the plane of practice, connecting cognitive, situated, and critical practice, and a second vertical axis connecting practice and infrastructure. This chapter explores the second axis.

Many programming languages and interfaces have been proposed for learning computer science (Guzdial, 2004; Kelleher & Pausch, 2005; Proctor & Blikstein, 2016), along with numerous frameworks synthesizing design research on the topic (Kelleher & Pausch, 2007; Resnick, 2017). However, when programming languages and interfaces designed for learning are viewed as literacy infrastructure, it becomes clear that most are designed to support programming as an individual cognitive activity. For example, Kelleher & Pausch's survey of programming languages and interfaces for teaching defines programming as "the act of assembling a set of symbols representing computational actions," allowing programmers to "express their intentions to the computer" and "predict the behavior of the computer" (2005, p. 83). Sociocultural constructs such as identity, interest, and participation have often been addressed in the

design of introductory programming environments, but these constructs are often framed as ancillary supports, not part of the main learning goal. (Counter-examples that frame programming as a fundamentally situated activity include computational participation (Burke et al., 2016) and debugging framed as situated inquiry (Flood, DeLiema, Harrer, & Abrahamson, 2018).)

In this chapter, I use an adaptation of rhetorical analysis to study how youth program with Unfold Studio, but I view the manipulation of programming syntax (and the computational ideas to which that syntax corresponds) as inseparable from the authors' social purposes. This approach is inspired by arguments in English/Language Arts for teaching grammar in context (Weaver, 1996). Proctor & Blikstein (2019) developed an analytical framework for studying how a literacy medium can support critical literacy practices. This follows a sequence of conjectures (Sandoval, 2014) linking Unfold Studio to mediating processes and then to outcomes framed in terms of critical transformation (identity authorship and channeling voice) and computer science knowledge and skills.

These conjectures are: that the perceived affordances of a computational medium could shape the rhetorical practices for which it is used; that these practices could shape the meanings and identities which are thereby enacted; and that these meanings and identities could open possibilities for critical understanding and activism. This chapter's analysis follows a four-layer analytical framework aligned with these hypotheses: affordances, rhetoric, figured meanings, and critical possibilities. Similar to Brooke's (2009) framework for analyzing digital rhetoric at the levels of code, practice, and

culture, each level permits analysis of the literacy place at a different scale. The following subsections address each conjecture in turn, grounding its approach in prior literature and explaining how it is operationalized in this research.

Affordances

The development of a literacy medium can be analyzed in terms of its affordances, or the ways it can be used to create meaning. The primary form of meaning-making this research considers is authors composing texts to shape the experiences of readers. A second form of meaning-making, important to the critical possibilities of literacy, is the way texts can open new possibilities for future authorship by expanding or redefining recognized genres. Norman (1999) distinguishes between affordances and perceived affordances—between the actionable properties of an object and those perceived as such by a user. When considering media which support literacy, this means distinguishing between the myriad ways a medium could potentially be taken up in meaning-making, and the subset authors perceive as likely to be recognized by an audience, within the context of the web application interface. Therefore, this chapter analyzes the perceived affordances of media through instances of their use.

The two media which interactive storytelling combines, text and code, function differently in supporting meaning-making, and therefore offer different affordances. Although in practice literacies are multi- and trans- (The New London Group, 1996; Thomas et al., 2007), there is value in distinguishing how reading a literary text differs from playing a computational artifact such as a game or an interactive map (Aarseth, 1997). One essential mechanism of text is representation. Representation can be achieved

in many ways, such as evoking sensory experiences through descriptive language, voicing characters through dialogue, and setting the mood through emotional descriptions of the setting. Rather than understanding representation as encoding some objective meaning, this framework takes a reader-response stance, viewing representation as offering provocations and opportunities to the reader. In Rosenblatt's (1968) account of reading as a unique, historically-grounded transaction between a reader and a text, each is transformed. (Thomas (2016) explores reader-response analysis of computational texts.) The reader's identity is changed through her response to the text, which then reciprocally transforms the text's possible meanings (Barthes, 1971).

One way we can interact with computation is through modeling or simulation. Interacting with computational models is a central practice in science (Blikstein, 2014; States, 2013) and computer science (K-12 Computer Science Framework, 2016). Interacting with a model can be agent-based, emphasizing how one actor in the system can affect others, or systemic, emphasizing emergent properties (Weintrop et al., 2016). Papert (1980) used the term microworlds to describe computational models or simulations in which one can immerse oneself and learn how the world works through play or exploration. This can lead to authentic, embodied knowledge, more like getting to know someone than learning a fact. For example, NetLogo (Wilensky, 1999) is an environment for modeling of dynamic systems. Participating in a NetLogo simulation can help students understand and predict the behavior of systems from both an agent-based and a system-level perspective (Wilensky & Stroup, 1999). I consider microworlds to be both models and games.

Interactive storytelling combines the affordances of text and code in ways that are difficult to classify, so the modes of interaction described in the previous two paragraphs are best understood as heuristics for the affordances authors might perceive in interactive storytelling, as instantiated in the web application's interface. Much of the participatory design process developing the web application was devoted to discovering the ways authors could use interactive storytelling and refining the interface and pedagogy to make those affordances more perceptible.

Rhetoric

The second design conjecture, centered on rhetoric, is focused on how authors use the affordances of media to create meaning. Theorists of digital rhetoric have argued for the importance of this link: whereas traditional literary criticism could assume some universality to how text functions, digital media cannot be understood apart from the affordances of its media (Bogost, 2007; Brooke, 2009; Francis, Johndan, Geoffrey, & others, 2004). Digital interfaces such as hypertext, interactive stories, Instagram, and mobile phones have such diverse affordances that the rhetorical possibilities of each are quite distinct.

The interactive storytelling community has identified several broad categories of rhetorical moves (Glassner, 2004; Montfort, Jackson-Mead, & Wheeler, 2011; Murray, 2017). Ryan (2001) contrasts immersion with interactivity. Reading a story can involve constructing a world of meanings around oneself through a transactional reading process. The reader potentially experiences immersion, a sense of being embodied in and surrounded by that world. In contrast, when playing an interactive story which functions

as a microworld, it does the work of simulation and its world is perceived as outside of oneself. The player experiences interactivity, with a heightened awareness of the interface. There may be a tradeoff between these rhetorical modes in interactive storytelling: the more the story handles the simulation (functioning as a microworld), the more one can interact with dynamics that are too hard to simulate or which one could not have imagined. The more the reader is left to do the simulation (as with a representational text), the more she can experience intimacy and empathy through immersive embodiment.

Figured meanings

The third design conjecture, figured meanings, describes the potential effects of rhetorical techniques used by interactive stories. These may include how others read the story and respond by reshaping their own identities, as well as reshaping the sense-making processes available for reading other texts. Following the earlier definition of identity as the interface between internal self-conception and externally-imposed subjectivities, changes to figured meanings may expand or contract the kinds of identities possible within the literacy place. As a concrete example, when a literature class reads texts featuring characters with potentially invisible life experiences such as being immigrants, queer, or homeless, these possible selves become more available to students' identities.

In the participatory design process, one common way interactive stories reshaped sense-making processes was by invoking existing genres or developing new genres. Genres include literary genres such as horror, science fiction, and role-playing games, as well as what Bahktin (1981) calls speech genres, or the "sphere[s] in which language is

used [and] develops its own relatively stable types" (p. 60). In their stories, participants used speech genres including quizzes, text messaging conversations, and Facebook posts. Story topics, such as family, friends, dating, and school, function similarly to speech genres in that they create expectations for the kinds of meanings that will be expressed. To be recognized, an author or speaker must adopt a register, a socially-recognized form of communication which indexes some qualities of the speaker (Agha, 2005). By introducing speech genres in their stories, participants pushed for social recognition of new registers within the literacy place.

Critical possibilities

Finally, the fourth set of conjectures is theoretical, linking critical computational literacy practices to the development of computational thinking and the possibility of critical change. I refer to critical literacy practices as those with the potential to enact transformation both within the literacy place (by changing the available subject positions or genres) and also beyond the literacy place (Gee, 2004). Fairclough (2004) refers to the performativity of texts as their "causal effects on nonsemiotic elements of the material, social, and mental worlds and the conditions of possibility for the performativity of texts" (p. 225).

When people find themselves within oppressive literacy places, where the existing language and cultural materials offer only marginalized subject positions, there are several possible responses. One might refuse to participate, retreating into the space of inner speech where for Bakhtin (if not for Vygotsky), one is free to fashion a self. One might also try to "use the master's tools to dismantle the master's house" (Lorde, 2003),

or insist on the inclusion of other materials, for example by legitimizing vernacular registers (Anzaldúa, 1987). Discovering and using critical strategies depends on understanding how identities are circumscribed by available subjectivities, and how registers are legitimized.

The goal of Freirian critical literacy is to develop this understanding. Freirian critical literacy depends on the representational function of text: once people become aware of the parallels between reading the word and reading the world, they may realize that neither has a fixed meaning, but rather the meanings of each are continually produced within a literacy place, and that the possible meanings are co-produced with one's identity. Of course, as mentioned earlier, it is much easier to open new possibilities for identity and register within a small discussion group than it is within the context of ideologies that span centuries and continents.

The computational affordances of interactive stories support additional critical possibilities (Blikstein, 2008; Bogost, 2006; Garcia, Mirra, Morrell, Martinez, & Scorza, 2015). One powerful dynamic which emerged in the participatory design workshops was using interactive stories to model literacy places themselves. For example, participants wrote stories allowing the player to experience how one is treated differently when speaking English versus Spanish, or how two friends in casual conversation can also be engaged in a struggle to position each other. These stories foreground otherwise-latent uses of power within the literacy place, making them visible and accessible for analysis and critique. These stories potentially function as critical discourse models, a particular

kind of what Vossoughi (2014) refers to as social analytic artifacts, or "tools that deepen the collective analysis of social problems" (p. 353).

Players of critical discourse models participate in the story's simulated literacy place. At the same time, the player and the story are both actors within a larger literacy place. The idea of a nested literacy place as an actor within a larger literacy place is not new: Bakhtin's (1981) multivocal understanding of texts in dialogue with existing meanings and Minsky's (1988) understanding of minds composed of many agents may each be understood as literacy places functioning as actors within larger literacy places. However, the distinct affordances of interactive stories (particularly the precision with which one can author them) offer unique critical possibilities.

Methods

This methods section builds on Chapter 3, where I report methods and context for the dissertation as a whole. Figure 4.1 presents the subset of Figure 3.5 from Chapter 3 which pertain to this research question.

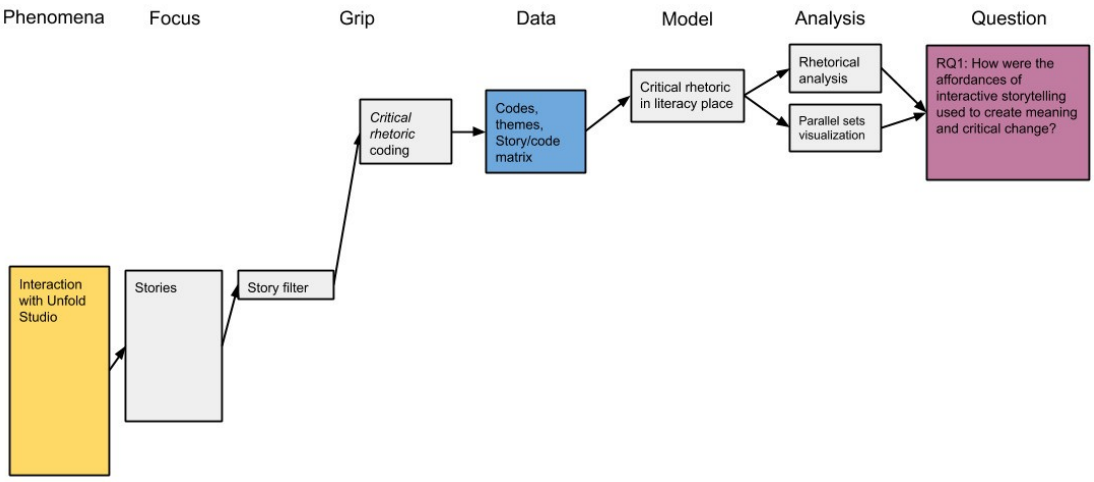

Figure 4.1: Overview of methods for RQ1

Focus

The 49 students who consented to participate in the study created a total of 2758 stories during the ten-week unit. However, the majority of these stories were either derivative or trivial. Students created derivative stories when they forked (made copies of) other stories and then made minimal changes, if they changed them at all. Sometimes students created derivative stories when they were asked to fork a template story during a lesson, but did not engage much with the lesson thereafter. A few students forked large numbers of stories in an attempt to boost the prominence of the parent story (stories are promoted to the front page according to an algorithm which includes the number of times they have been forked), or out of idle curiosity: Two students told me they forked a story over and over just to see what would happen. The second category of discarded stories, trivial stories, were very short. Students often created these as "scratch pads" to take notes or to test out an idea. Neither derivative nor trivial stories represent much concerted effort on students' part which did not end up in more substantial stories. Therefore, I used an automated filter to remove stories according to the following rules:

- Derivative stories were forked from another story and too similar to the parent (using the ratio Levenshtein distance / alignment length <= 0.99 as implemented in the python *fuzzywuzzy* package; this excluded 39% of users' stories). This score gives a measure of how much overlap exists between two stories, taking their length. Changing the cutoff value had little effect on which stories were excluded.
- Trivial stories were very short (having fewer than 40 tokens; this excluded 40% of stories). I tried different cutoff values and found 40 to be fairly conservative: I spot-checked the excluded stories and none were interesting for these research questions.

After the automated filtering pass, there were a total of 677 stories. I then did an initial pass of coding to identify additional stories which should be excluded because they were unfinished fragments, near duplicates of other stories, or otherwise uninteresting (e.g. one line copied over and over). After manual filtering, 578 stories remained in the final corpus.

Grip

I coded stories using QC, applying codes to lines but treating the story as the unit of analysis. This allowed me to review the specific text to which I applied codes, while computing the cross-tabulation analysis reported below at the unit of the story. To be clear, when quantities of codes are reported in this chapter, it is a count of the number of stories containing that code or one of its child codes at least once. I decided on this unit of analysis because most of the stories I coded were reasonably unified and coherent, so that qualities coded at different points in the story generally interacted with one another. For example, one story used characterization to develop the player's character and then denied the player agency by limiting the player's choices, as a way of exploring the dynamics of peer pressure. The characterization, the denial of agency and the peer pressure likely contribute to the same holistic reading experience. Furthermore, I did not feel that the density of my coding within stories was particularly reliable. I felt much more comfortable saying *that* a story contained a particular code than I did quantifying its presence in the story. The impact of story elements on a reader's experience is not proportional to the number of words or sentences through which it is realized.

I began by coding approximately 50 stories in a random order, followed by a substantial revision of the codebook (described below). I then switched to coding all participants' final story submissions (37 total) to ensure that their most substantial stories were included, and then I continued coding randomly. I found it unmanageable to code all of stories, so I decided to code to saturation, or the point where most of the stories I encountered fit within the logic of existing codes. In total, I coded 241 of the 578 stories.

While I used an open coding strategy (e.g. I was not restricted to an a priori set of codes), my coding was oriented to the analytical framework from Proctor & Blikstein (2019), and I began by referring to that study's codebook. Because I did not use an a priori coding scheme, I generated a tremendous number of "fuzzy" codes (over 1000 distinct codes) which were often redundant or which reflected conceptual categories which had not yet stabilized. As an example, here is a selection of codes from midway through the coding process, after I had coded a substantial number of stories but before the first major refinement of the codebook:

- choosing_future
- choosing_identity
- choosing_identity_in_game
- choosing_in_game_identity
- choosing_self_in_game
- choosing_world
- identity_authorship_in_world
- identity_in_story
- identity_in_world
- imagined_future
- in_game_identity_authorship

Some of these are clearly redundant (e.g. “choosing_identity_in_game” and “choosing_in_game_identity”), and nothing is lost by globally replacing one with the other. However, other cases raise more substantial questions. Considering the difference, for example, between “in_game_identity_authorship,” “choosing_identity_in_game,” and “choosing_self_in_game” required consideration of how I understand the concepts of self and identity, and whether making choices about in-game identity sometimes or always qualifies as identity authorship. I do not use the term ‘self’ in a technical way, and making choices about a character’s in-game identity can be a form of identity authorship for the player of the game. Even if no other participants in the literacy place become aware of the player having made such a choice, it could be an opportunity to practice making a scary decision and to reify an identity to oneself. Furthermore, presenting certain choices to a player is often a form of identity authorship or voice for the story’s author.

I often worked out this sort of thinking by reviewing the text to which various codes were applied, and wrote about my thinking in integrative memos (as recommended by Emerson, Fretz, & Shaw (2011)) which became the basis of the analysis presented later in this chapter. Then, once I had resolved how to interpret my coding, I reorganized the codebook to reflect my thinking. I made “choosing_identity_in_game” a child code of “in_game_identity_authorship,” so that whenever I counted or searched for the parent, the child codes would be included. There were situations where it was valuable to keep these codes distinct, for example if I later wanted to be able to focus on the reader’s act of

making choices, or the author's crafting of these choices. Because this reorganization of codes was ongoing and retroactive, I did not find it necessary to finalize my codebook and then re-code the corpus with the finalized codebook.

In addition to manual coding, I wrote programs to automatically code two classes of features:

1. Syntactic constructs from the Ink language. I automatically coded when stories contained variable declarations, random numbers, and tunnels (divert statements where the current context is pushed onto the call stack, so that control will return to the current knot), among others.
2. Graph structures such as multiedges (two diverts from a knot which both go the same destination, often used to create the illusion of choice), cycles (stories containing paths which loop back to previous content, and several measures of graph complexity.

To keep these automatically-generated codes in proportion with manual codes, I report only those applied to stories which were also manually coded.

Data

The primary data used in answering this chapter's research question is the codes and memos which emerged from the coding process, as well as coded excerpts from stories. Because this chapter focuses on the practices of the cohort as a whole, counts of codes and their co-occurrence within stories were also important. I used QC's cross-tabulation feature to generate matrices of co-occurrence of selected codes, using the document as the unit of analysis, and recursively including the occurrence of child codes. Therefore, the cross-tabulation score for two codes is the number of stories in which each code (or one of its child codes) occurs.

Model

The critical rhetoric framework developed in (Proctor & Blikstein, 2019) provides an outline of how authors make meaning within a literacy place: (1) They use the affordances of the medium (2) for rhetorical effect, which (3) addresses certain figured meanings, and (4) possibly changes the conditions for future meaning-making by altering subject positions, genres, and the figured meanings of other texts. These phases were the a priori top-level codes in my codebook; emergent lower-level codes represented ways in which each phase was enacted.

Analysis

This chapter's research question is particularly interested in relationships between codes at different phases of the analytical framework (for example, which affordances tended to be used in which rhetorical strategies). Drawing on the memos I wrote during coding, I analyze patterns of co-occurrence which were prevalent in the corpus and which were theoretically generative. Parallel sets (Kosara et al. (2006)) are an effective visualization strategy for this structure. Codes of interest are aligned on parallel vertical dimensions (affordances, rhetoric, figured meanings, critical possibilities), and links between codes represent code co-occurrence. The widths of codes and links between codes are proportional to their frequency.

Results

Overall structure of meaning-making processes

A subset of the final codes is shown as a parallel sets diagram in Figure 4.2. Codes are organized into columns representing the layers in the analytical framework: affordances,

rhetoric, figured meanings, and critical possibilities. The vertical height of each code's bar is proportional to the number of stories containing that code or one of its children. The links between codes represent stories being coded with both the source and the destination code. (As with codes, the width of links is proportional to the number of stories having both codes.) These links are of particular importance for this chapter's research question, as they represent connections between layers of the analytical framework. For example, one can see at a glance that somewhat more of the stories using rhetorical strategies related to immersion were coded with figured meanings than stories using rhetorical strategies related to interactivity. This suggests that when authors want to talk about a particular topic, they more often wrote stories that immersed the reader in the world of that topic than creating interactive simulations of the topic's dynamics.

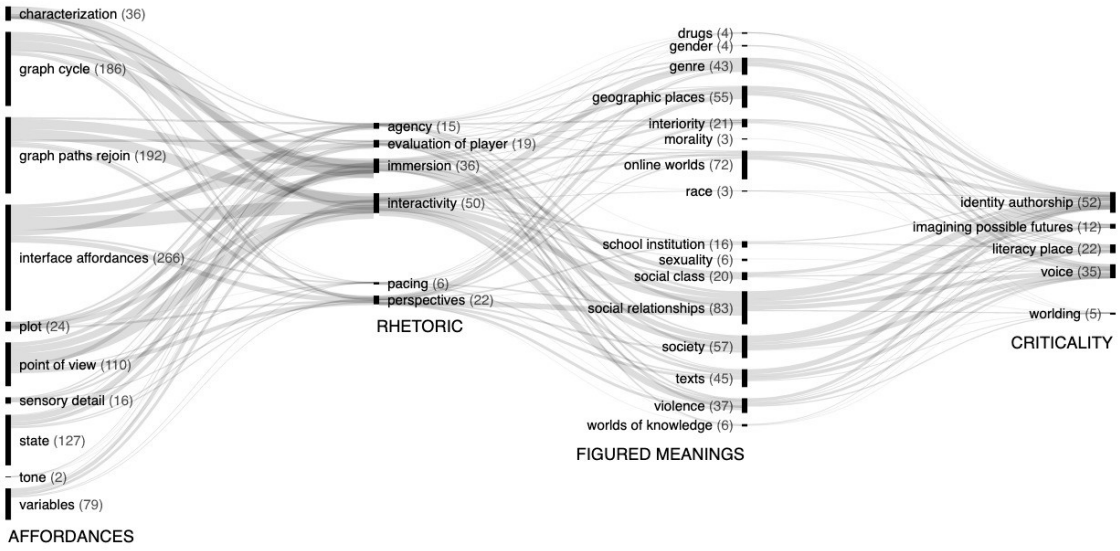

Figure 4.2: Summary diagram of four layers of meaning-making

The following subsections of results address particular dynamics between layers of the analytical framework. Each presents an example illustrating the dynamic as well as a parallel sets diagram showing its relative prevalence in the corpus.

Rhetorical uses of computational affordances

Because interactive stories are also computer programs, authors could make use of computational elements alongside traditional literary elements. Two high-level categories of computational affordances are *flow* and *state*. Flow refers to the nonlinear character of interactive stories, and includes specific codes such as "graph_cycle" (when the story graph includes a loop) and "graph_paths_rejoin" (when the story graph splits and later rejoins). Authors usually made use of flow by using diverts to redirect the flow of the story. State refers to the ability of the story to keep track of what has happened in the story. The Ink language provides mechanisms for implicit and explicit use of state. State can be used implicitly by using once-only options or by checking the number of times a knot has been visited. State can be used explicitly by assigning and checking the values of variables. Additionally, Unfold Studio offers interface affordances such as the ability to style certain lines of text to look like text messages (see Figure 4.3), and the ability to use HTML markup within the story's text. In one extreme example, an author from another school implemented a web application with a graphical user interface within an Unfold Studio story.

```
OUT OF NOWHERE JEFFERY TXT'S LARRY

Jeffery: Yo, bro, i got T for u and abt u #text-them
Larry: Wuzz up? #text-me
Jeffery: ok so u know that Molly girl...?! #text-them
Larry: umm...yea..y? #text-me
Jeffery: bc...there's ppl saying she likes u and u
    might like her..is that true...? #text-them
Larry: who said that cause its not true and i cant
    even txt Molly and show u #text-me
Jeffery: Bob & Jewls were saying that. and she will
    denie it..🙄😉 #text-them
Larry: No she wont. #text-me
Larry: ill ask rn and ss if u dont believe me. #text
    -me
Jeffery: ok u do that #text-them

LARRY WENT TO TXT MOLLY

Larry: hey...i have a question... #text-them
Molly: yeah wuzz up #text-me
Larry: so..my friend Jeffery was saying sumthing..and
    i wanted to know if it was true...#text-them
Molly: yeah..ok..? wuzz up....? #text-me
Larry: so Jeffery asked if u and me were "a thing..."
    & if u liked me.. and i told him u dont. And he
    said ok like in a weird way so then i told him i
    would ask u..and he said that u will dene it
    ...#text-them
Molly: oh.....umm...well...i mean like as a friend
    ..? #text-me
Larry: like more than a friends.. #text-them
Molly: oh....umm...maybe a little bit...but like idk
    .... #text-me
Larry: ohhh...umm...ok then..😬😬..umm...i gtg....
    #text-them
```

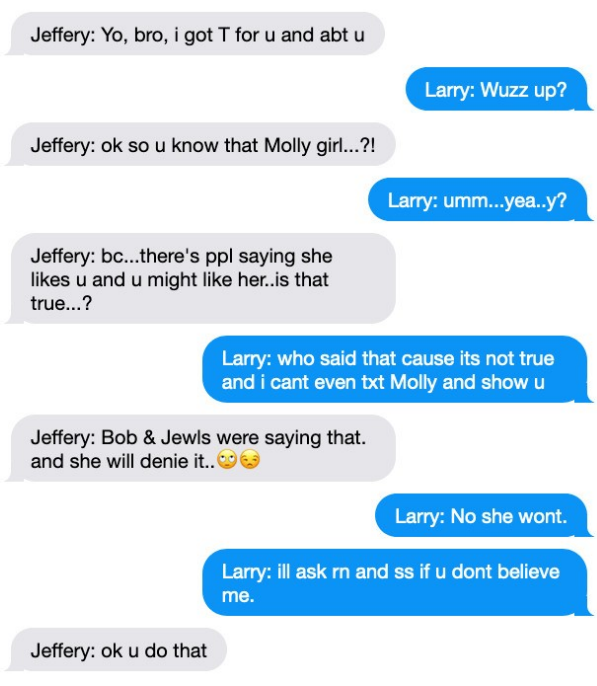

Figure 4.3: Excerpt from “Larry & good friend” by Emilia

In “Larry & good friend” (Figure 4.3), Emilia writes a social drama in which Larry and Molly develop a close friendship while resisting other characters’ efforts to define the relationship in romantic terms. The story takes place largely through text messaging exchanges between characters in a voice rich in acronyms and emoji. Neither state nor flow are used much in this story, but Emilia makes rich use of the computational infrastructure from existing discourse in her social world. Because Unfold Studio allows authors to enact interfaces like text messaging in their stories, authors can represent and critique semiotic processes unique to the medium. In Figure 4.3, the text messaging allows for several different private conversations to be interleaved so that we can watch Larry reposition himself in response to his “bro’s” inquiries about his feelings for Molly, and then in his conversation with Molly.

The emoji, acronyms, and ellipses allow for ambiguity in communication which nevertheless points to feelings that can be hard to express directly. For example, Jeffery uses the emoji “ ” to distance himself from the rumor that Larry and Molly like each other, even as he asks about it. After Larry asks Molly whether she likes him “more than a friend” and she replies with “umm…maybe a little bit…but like idk,” Larry’s disappointed response is “umm…ok then.. ..umm…i gtg….” Subtext works differently in text messaging: our repertoire of body language, facial expressions, and gestures are replaced with emoji and implied gestures encoded in acronyms which are overburdened with the responsibility of functioning simultaneously as text and subtext. We insert them into the text, while implicily asking our interlocutors to accept them as a form of iconicity, an involuntarily disclosure of internal state akin to a giggle or a grimace.

Meanwhile, Larry has offered to document his conversation with Molly by taking a screenshot (“ill ask rn and ss if u dont believe me”) to show Jeffery that there is nothing beyond friendship between him and Molly. Yet Larry hopes there is a spark, and when he gets an inconclusive response from Molly he turns back to Jeffery to discuss the situation. What is important here is that the identity authorship and relational dynamics in this story are shaped by the text-messaging medium. They would be lost in translation to conventional literary writing. Having some of the same computational infrastructure available for storytelling as authors rely on for their real-live social practices makes it possible for storytelling to perform its crucial role of representing, imagining, discussing,

and critiquing social situations from a distance. Proctor & Blikstein (2019) referred to this as a critical discourse model.

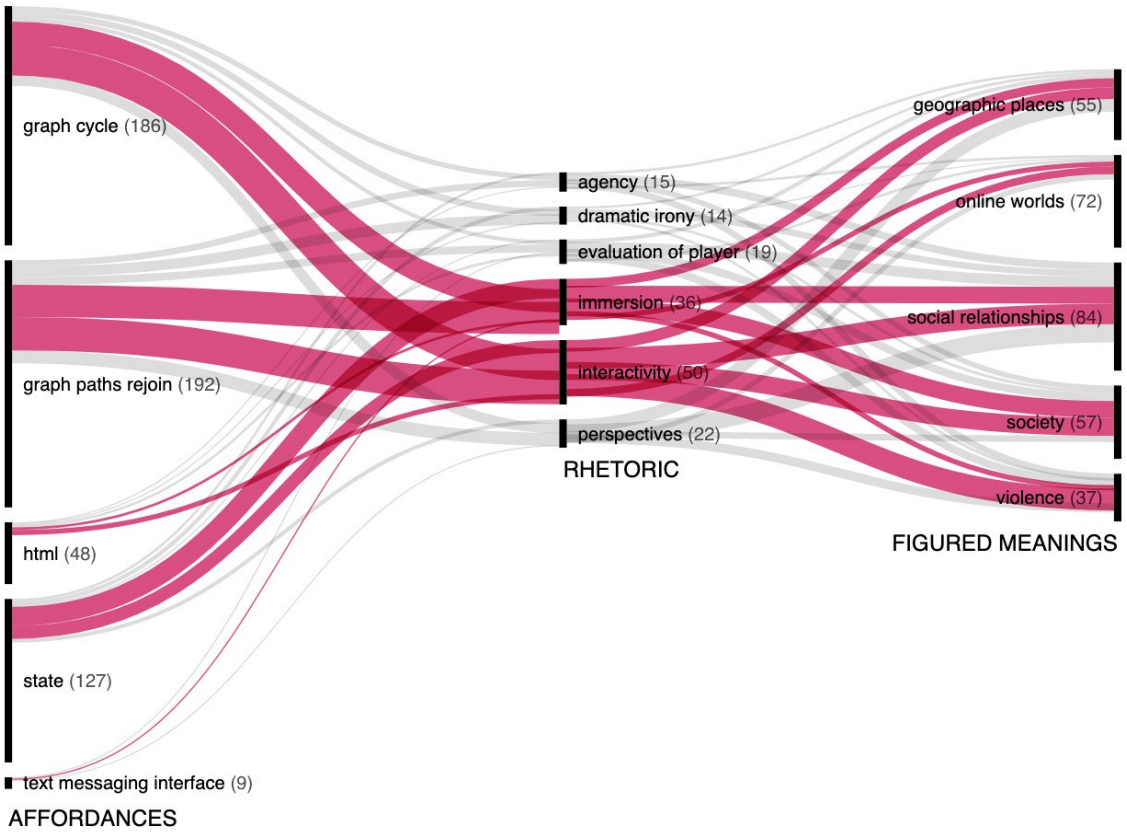

Figure 4.4: Parallel sets diagram showing use of computational affordances. Note the frequent rhetorical use of immersion and interactivity.

Figure 4.4 shows how various computational affordances were put to use rhetorically to address various figured meanings. Just as with the text-messaging interface above, authors often used other computational affordances as a shared basis on which to connect to their existing literacy practices. This was particularly notable in their use of immersion and interactivity (highlighted in Figure 4.4), two distinctive modes of connecting with digital media. However, it is somewhat surprising that these affordances

were seldom used in stories dealing with online worlds. One possible explanation for this is that many of the online worlds discussed, such as Fortnite and Minecraft, are highly visual, and Ink's affordances felt inadequate to represent interactions in those worlds. In future research, I will explore whether adding richer affordances for writing fictional tweets or Instagram posts helps students write stories grounded in those worlds.

Critical uses of point of view

One notable difference between conventional literary writing and the interactive stories written during this unit is the prevalence of first and second person point of view. Third person point of view is by far the dominant point of view in conventional fiction and creative nonfiction. First person is often harmfully stigmatized as unacademic (Ivanič, 1998), and requires authorial skill to develop a first person in-story identity distinct from the author's identity in the literacy place. Additionally, it requires skill and a social consensus on the part of the audience to make this distinction. Second person is rare in most literary writing. In contrast, second person was the dominant point of view in these stories, followed by first person. One reason for this could be that in conventional literary writing, it can be harder to comprehend the reader's in-story position and role in co-constituting its meaning. With interactive storytelling, there is more for the reader to do, making the reader more available to be positioned, provoked, or addressed by the author.

```
3  === part1 ===
4  so today im going to tell you something thats kind of scary for me to tell.
5  so whenever i go out somewhere with family its like i get all the attention
       because im black.
6  -> q1
7
8  ===q1===
9  did i do something
10 +they said nothing.
11 ->DONE
12 +someone said no.
13 so i asked is there a problem
14 ->q2
15 ===q2===
16 is ther a problem.
17 + someone said no.
18 -> DONE
19 + someone said your fine
20 ->part2
```

Figure 4.5: Excerpt from "Young, Gifted, and Black" by Isaiah

For example, Figure 4.5 shows an excerpt from "Young, Gifted, and Black." The story starts in first person with the speaker addressing the reader ("so today im going to tell you something…") and marking the story to come as important to the speaker. As we drop into the narrative, the story remains in first person. When the first choice is presented, the player's position within the story shifts from being addressed by the speaker (as audience) to making choices about how the anonymous "they" or "someone," presumably directing uncomfortable negative attention at the speaker. This other remains anonymous and undefined; the only remaining role for the player is to inhabit the "I," making available a reading in which the story is understood to shift to first person. The effect of such a reading is to encourage empathy on the player's part with the discomfort of being the center of negative attention which nobody will admit exists. At the same time, the player must make choices about what "somebody" says, creating the effect of paranoia, close attunement to a racial threat which is felt but which never comes sharply

into focus. Although this is a short example from a fragmentary story, it powerfully illustrates how point of view can be used to author texts with critical possibilities. In this case, Isaiah used point of view to deploy a real-world identity and subject position as in-game resources, generously offering his experience as a model for others who might not have had such experiences.

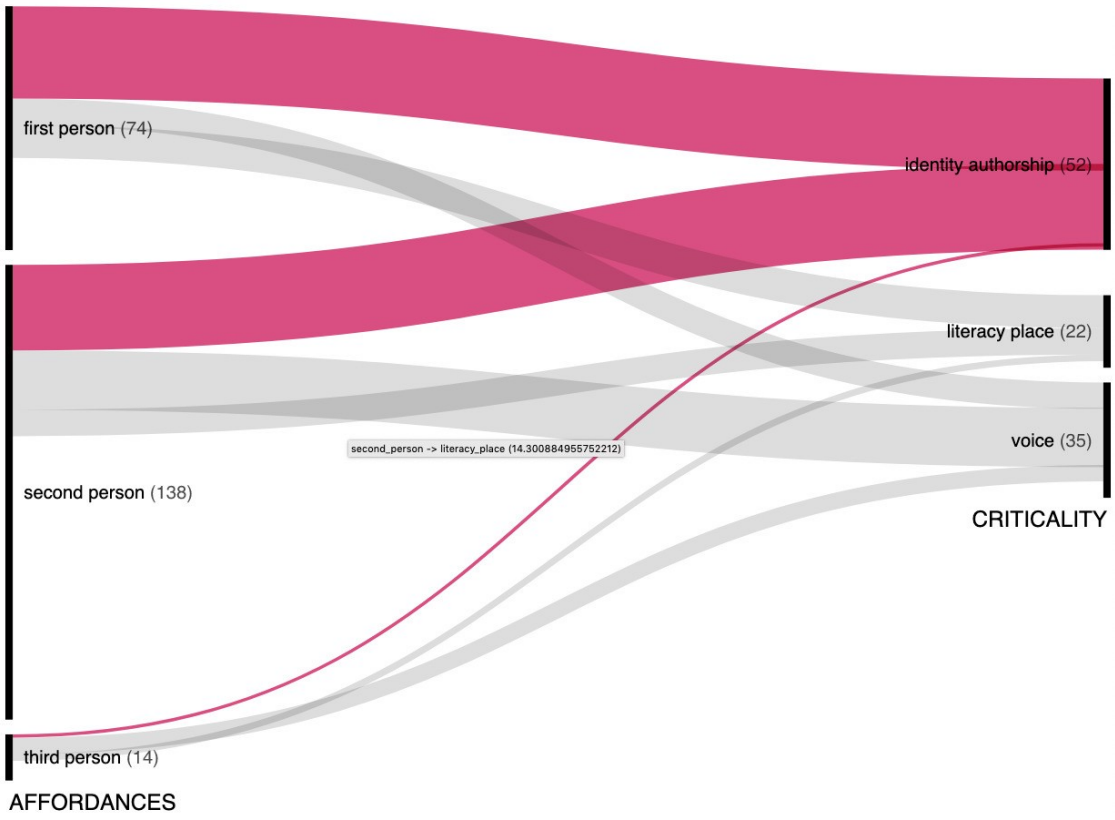

Figure 4.6: Parallel sets diagram showing point of view and critical possibilities. First- and second-person were used heavily in identity authorship.

The story above is emblematic of a broader trend shown in Figure 4.6, that stories coded as engaging in identity authorship were predominantly written in first or second person. Writing in the first person potentially positions the real-life author as the story's

voice, and also potentially invites the reader into a more intimate position with respect to the author. When the story is written in first person, the player occupies the story's "I," which, as in the story above might also be associated with the author. When a story is written in second person, the player occupies the story's "you," which makes the player vulnerable to the in-game speaking voice or to the author, who has the freedom to define the player's in-game identity or to compel the player to take actions. For example, in some second-person stories the speaker occupies the position of "dungeon master," speaking to the player with omniscience and omnipotence. Sometimes this is used rhetorically to reinforce that the player is in a world under control of the speaker. Other times the speaker takes a reflective tone, interpreting the significance of what the player is experiencing. The third person, in contrast, offers fewer dynamic relationships between author and player, and puts less at stake.

This at-stakeness might afford some moves in the story while closing off others. Intimacy and vulnerability invite the player to take the story more seriously as a player and as a peer of the author. But they might also expose the author and create inequities in which authors feel comfortable sharing painful experiences or those which might get them in trouble. Proctor & Garcia (2020) discuss the value of the ambiguity offered by nonlinear narrative for supporting student voice, particularly when students occupy marginalized subject positions within the school. (When the story can end two different ways, the author is somewhat insulated from questions about whether the story "really happened.")

Fourteen stories were coded as both first person and second person, shifting in their point of view. This often happened when when moving from the framing to the gameplay, as the authorial first-person addressed the reader and introduced the story. Other stories subtly accomplish the same move in a manner that is possible in literary writing, describing inner feelings using second person, and then switching to first person to "own" the experience. For example, in one of Rasputin's stories, they write, "lets start with this. feelings suck. that feeling when you get a crush on a girl who doesn't like girls?" Rasputin continues to develop the situation in the second person before switching back to the first person to reflect on its significance.

Though it is not always obvious, different media have different affordances for point of view. For example, it is hard to imagine how Scratch, with its dominant interface metaphor of theater or film, could easily support first- or second-person point of view. Furthermore, prose as a cultural form (Horn, 2013) is much more closely associated with first-person, introspective writing. If, as this analysis suggests, writing in first- and second person indeed supports criticality through identity authorship and voice, this could be an important insight for the design of future computational media.

Manipulating player agency

Manipulating player agency played an important rhetorical role in many of the stories which most powerfully feature critical transformation of figured meanings. For example, in "Couples therapy" (Figure 4.7), Amy crafts an intricately-plotted account in which "you are at couples therapy with your significant other because you two are having the nothing fight." Much of the story's power comes from the way it presents options to the

player, and then reacts to the player's choices. In the excerpt below, the therapist proposes to use astrology to explain the couple's problem. The player must choose whether to "listen nicely" or to argue with the therapist. If the player chooses the former, "You listen nicely and all your problems were solved," at which point the story abruptly ends, cutting off the remaining two-thirds of the story.

```
==explain==
You explain that you and your significant other are having the nothing fight and don't know
    how to solve it. She starts talking about zodiac compatibility. You can listen nicely
    or start to argue with her.

+Start to argue with her
->argue
+Listen nicely
->listen

==listen==
You listen nicely and all your problems were solved.

->END

==argue==
You start to argue and say,
"This has nothing to do with Pisces hating Aries or Aquarius hating Capricorn, or everybody
    hating Gemini, this is about two people having a problem and needing it solved."
Then she asks both of you to take a lie detector test.
```

Figure 4.7: Excerpt from "Couples therapy" by Amy

The dead end is itself a rhetorical strategy. (It is easy to replay stories on Unfold Studio.) The dead end sometimes suggests that a choice is outside the bounds of what is acceptable, proper, or reasonable in the story world. In some more violent stories, character death is used in a similar manner. In this case, the dead end comes with tart contempt of docile femininity. That said, there are several other dead ends in the story which follow the player's decision to walk out on therapy and give up on the relationship. In trying to find one's way successfully through to the end of the story, a player needs to make choices which balance meeting the character's individual needs with preserving the

relationship. (Navigating a story full of dead ends became a common reading practice within the class. Sometimes readers would toggle open the code to explore the program flow while they played.)

The sarcasm running through this story is connected to several other common rhetorical moves such as the interjection of the speaker to comment on a player's actions, or the use of dramatic irony to more subtly create the same effect of interpreting the meaning of the player's choices. These can be important forms of voice, reconfiguring the meanings of identities, texts, and speech genres.

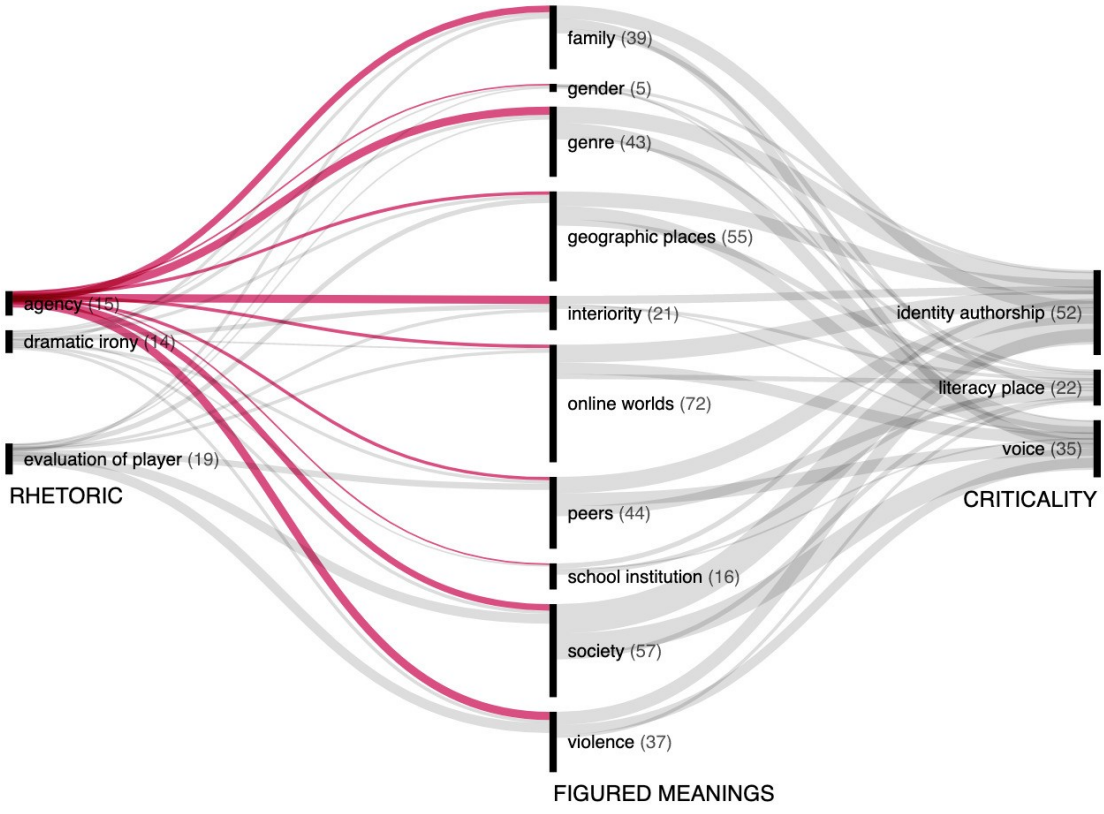

Figure 4.8: Parallel sets diagram showing rhetorical uses of agency.

While "Couples therapy" cultivates the player's agency, other stories work by denying the character agency, either to force the story to a particular plot point or to compel the player to take an action or to remain passive, thereby positioning the player as a witness, a passive bystander, or implicated in an action. For example, Proctor & Blikstein (2019) analyze how an author denies the player the agency to intervene when a friend is bullied, thereby forcing the player to confront guilt and shame.

In other stories, the player's agency is detached from character agency. For example, in one story the player is a (presumably) middle-school girl who has a crush on a boy. The story starts off with the choice of how to trip when seeing your crush. It is ambiguous whether the player is in this situation making a choice as the in-game character (e.g. intentionally tripping while pretending not to), or as the reader of the story choosing how the story world should progress (e.g. imagining different futures in which the player accidentally trips in different ways). In either case, the player can succeed in tripping so that she falls into the boy's arms, or she can trip inartfully onto the floor, causing the boy to laugh at her. Negotiating this agency (to what extent was tripping intentional?) runs parallel to negotiating one's own interior sense of emotional agency: when do we choose what we are feeling? When are we unable to control it? When we do something we want to do but know we should not, to what extent is it a conscious choice?

Discussion

Even if these results are persuasive in showing that the interactive storytelling analyzed here had intrinsic value as literacy practices, the results have not addressed a question raised in the introduction to this chapter: should the interactive storytelling practices

described above be seen as promising for learning programming, computational thinking, or for computer science education more generally? I believe a strong case could be made for viewing the writing practices analyzed above as computer science concepts such as sequencing, state, and computational modeling, but the more challenging issue with answering this question is that despite sustained attention over the last decade, the question of what exactly constitutes core skills and knowledge in computer science or computational thinking remains unresolved (Grover & Pea, 2013).

Denning (2017) argues that more precision is needed in defining computational thinking, but I want to argue in favor of less precision in a priori definitions. After we argued for the utility of distinguishing cognitive, situated, and critical computational thinking (Kafai et al., 2019), we argued that it might be better to replace all three categories of *computational thinking* with *computational literacy*, which better-articulates their relationship to one another. Even the most minute acts of programming take place within a situated understanding of what kinds of problems are worthwhile and what kinds of approaches are valuable. Critical questions about how worthiness and value are defined are also always potentially present. Instead of trying to define too precisely what counts, this chapter offers a descriptive analysis of the kinds of practices that came to count.

There were numerous examples of authors "changing what counts" by making use of Unfold Studio or the Ink language in new ways. Norman (Norman, 1999) considers perceived affordances to be a subset of affordances: of all the ways you could act on an object, you will only recognize some of them. However, in the context of rhetoric (or

semiotics more generally), action exists only where it (potentially) has an effect. Similarly, a symbol only exists when it is understood to signify. It might be that in some genres, starting a sentence with a vowel implies that the sentence should be understood as sarcastic. I have never encountered this convention. For me, then, this affordance does not exist. If I were to perceive it as a potential way of making meaning (perhaps by recognizing existing social practice), the perception of the technique as having rhetorical potential would come prior to its existence as an affordance.

The perception of affordances which are not yet in use are an important mechanism by which genres can be rewritten. I understand such transformation as a fine-grained mechanism of channeling voices. As I described in Chapter 2, I understand voice as a distinctive form of expression linked with identity, felt to be part of oneself, and dialogically defined by and constrained by recognized genres. Voice is closely-connected to audience, as audience becomes addressable through voice and voice is reified by being received by audience. Channeling voices is the process of transforming genres to make possible voices that feel right and which allow one to be heard. This chapter showed how channeling voices involves engagement with and transformation of the infrastructural literacy medium.

This fine granularity may be useful for analyzing the relationship between the two forms of criticality I identified in Chapter 2 as axes of literacy: transforming situated practice by re-situating it in new subject positions and genres; and engagement with media infrastructure. Both forms of criticality have been identified as important in critical media literacy (Gutiérrez et al., 2019; Lynch, 2019), but I have not seen them previously

unified with an analysis of the ways subject positions and genres are enacted through infrastructure, and therefore vulnerable to transformation at the level of infrastructure.

How might we extend the design goal of "programming languages for learning" to a goal of designing interfaces to support critical computational literacies? One promising strategy is to make the medium malleable. Over the course of the design-based research during which Unfold Studio was created, it was helpful that the interface appeared to users as unfinished. Writing workshops always included meta-discussion about how Unfold Studio worked, and how we should change it. As Unfold Studio has matured and begun to be used in classrooms with which I have no direct connection, it has become less feasible to include the web app's users in its development (though it will continue to be developed as an open source project on GitHub, and I hope to cultivate ongoing teacher and student participation similar to users' participation discussing features and policies on the Scratch forums).

Even if authors' ability to change Unfold Studio must lessen over time, the medium can retain malleable by making infrastructural connections to other literacy places, such as social media and digital game worlds. The excerpt from Emilia's story (shown in Figure 4.3) used the affordance of text message speech bubbles to incorporate rhetorical techniques and genres which might not otherwise have found purchase in an interactive story. Future affordances supporting fictional tweets, Instagram posts, and discourse from other digital platforms could have a similar effect of enriching the storytelling possibilities within Unfold Studio while creating a place for critical examination of other digital media worlds. "New media invites us to rethink (or reinvent)

the canons of classical rhetoric; understanding them as practices that might, in turn, be used to understand the proliferation of interfaces that surround us" (p. xiii)" (Brooke, 2009, p. xiii). Making media interfaces malleable is directly parallel to Bakhtin's (Bakhtin, 1981) concept of novelization. The novel destabilized other genres by incorporating them into a form (the novel) where they "become dialogized, permeated with laughter, irony, humor, elements of self-parody and finally… an indeterminacy, a certain semantic openendedness, a living contact with unfinished, still-evolving contemporary reality (the openended present)" (p. 7). Unfold Studio could support similar novelization of digital media genres which currently discourage their users from critical engagement.

Conclusion

This chapter explored the design question of how authors used the affordances of Unfold Studio and the Ink language to write rhetorically- and critically-powerful stories which could affect their readers and open new possibilities for identity and voice in the literacy space. The next chapter builds on these findings by looking closely at several case studies of how reading and writing interactive stories allowed them to connect existing literacies to the classroom literacy place, and in doing so, to transform the school literacy place's subject positions and genres to allow for new forms of identity authorship and voice.

RQ2: Connecting across literacies

Introduction

What is it like to write interactive fiction? Chapter 4 showed broadly how students made rhetorical use of the affordances of Ink and Unfold Studio to create figured meanings and critical possibilities. This chapter is focused on the experiences of two focus students who are marginalized in different ways at school, and who participate in different literacy practices out of school. Each navigated school and out-of-school literacy practices differently, bringing resources into each other to author identities and develop voice. I also analyze a contrasting case: a student who used many of the same techniques to connect in-school and out-of-school literacies, but not toward critical ends. Rather, he used interactive storytelling to transplant his family's high socioeconomic status into a privileged position within the literacy place. Connecting across literacies can create learning opportunities and make available important identity resources, but it can just as easily import and amplify inequities.

Background

This chapter analyzes several focus students' efforts to make room for identities and voices they wanted in the school-based literacy place. Chapter 2 developed the structure of a literacy place, as well as two forms of critical action: identity authorship and channeling voices. I understand identity authorship as developing the interface between private, internal meanings (which might be deeply grounded in worlds outside the school, but which are not necessarily visible at school), and the subject positions made available

and imposed on them by the school world. When the focus students chose to include their religion or gender identity in the stories they were writing, they were not just writing stories, they were also authoring the identities that defined how they were figured within the literacy place. When these identities were not available within the literacy place's subject positions, writing stories with characters occupying new subject positions, and voicing new genres, helped to change the literacy place. Identities are figured answers to the question, "Who are you?" and voices are figured answers to the question, "How do you speak?"

The New London Group (1996) argued for reconceptualizing literacy as *multiliteracies*. We all participate in multiple literacy places, practicing different kinds of literacy with and for different audiences, and via different forms of texts and media. Sometimes we move between literacies, as when we go from home to school. But often we engage in multiple literacies simultaneously, particularly when different kinds of space overlap one another. (For example, Ito & Okabe (2005) describes how Japanese teens use cell phones to participate in *technosocial situations*, physical/digital spaces where they can disrupt adults' efforts to control them.) Drawing on the broader dissertation framework of literacy places as figured worlds, this chapter focuses specifically on how individuals used Unfold Studio to bring their existing literacies into the classroom literacy place. I am also interested in how uptake may have gone the other direction, how students appropriated ideas and practices from computer science in their out-of-school literacies, and how shared affordances of the infrastructural media may have facilitated movement in both directions.

Expanding literacy into multiliteracies raises questions about how participants move between literacies. When we begin to participate in a new literacy place, to what extent and under what conditions can we author identities and channel voices familiar from other literacies? The dialogic nature of identity and voice suggests that when there is substantial overlap in participants between new and existing literacies, the overlapping cohort may be prepared to recognize familiar subject positions and genres. Another possibility I explore in this chapter is that shared media infrastructure (specifically, similarities between interactive storytelling and the digital media of informal out-of-school literacies) could support connections across literacies. diSessa's (2001) analysis of how media technologies encode social niches and genres, and his term *social material intelligence* for knowing how to interact with them, could be extended to a multiliteracies perspective asking how familiar media supports participation in new literacy places.

The Connected Learning Framework (Ito et al., 2013) calls for connecting in-school learning to concrete out-of-school opportunities, and highlights the role of digital media n "link[ing] a broader and more diverse range of culture, knowledge, and expertise to educational opportunity" (p. 6). The framework points out the importance of digital learning opportunities and the stark inequities non-dominant youth face in accessing them, and proposes bridging a "culture gap" (Collins & Halverson, 2009) between academic and informal genres. My work builds on and is inspired by connected learning, but I wish the its focus on building bridges were accompanied by a critical dialogic stance toward the "academic sphere." The framework closely associates dominant academic literacies with economic opportunity in ways that are particularly problematic

for computer science, where high-status subject positions remain bound to racial, gender, and social class categories. Drawing on critical pedagogy and critical race theory, Vakil (2018) celebrates scholarship focused on equity in computer science education while arguing that it does not go far enough in challenging dominant conceptualizations of computer science. I share the Connected Learning Framework's goal of "educational, economic, and political opportunity" (p. 61), but believe we focus too much on entry points when the dominant practices themselves are fundamentally framed in marginalizing terms. When youth do not perceive the academic sphere, oriented toward "future success, opportunity, and access to sites of power," to have a place for them, it needs to be transformed. One contribution I hope to make in this chapter is an analysis of critical practices through which participants make room in dominant literacies for their identities and voices.

This chapter's focus on connecting literacies through identity authorship and voice is similar in important ways to Gresalfi & Hand (2019), whose design-based research aims to connect two views of identity in theory and in classroom practice. From the point of view of the discipline of mathematics, students have disciplinary identities which position them and afford more or fewer opportunities to participate. From the point of the view of marginalized students, participation in mathematics is risky because "mathematics, as it is realized in schools, positions students from socially minoritized backgrounds as less capable mathematically, and ultimately, less intelligent" (p. 493). Gresalfi & Hand articulate a view of identity very similar to that developed in Chapter 2, and discuss *norms*, *frames*, and *narratives* as resources for identity construction in ways

which are compatible with my discussion of subject positions and genres. One way this chapter builds on Gresalfi & Hand's framework of mathematical identity is the centrality of computational media (code and interfaces enacting code) to computer science. This emphasis on infrastructural media is the basis for my selection of literacy as a primary conceptual lens and my dialogic view of identity authorship and channeling voices. I am inspired by Gresalfi & Hand's proposal that critical engagement with oppression in the domain of mathematics could support broader efforts at resisting and subverting oppression. The methods I use in this chapter, which center interactions with text rather than classroom discourse, provide visibility how engagement with media can support connecting across literacies.

Research questions

1. How did participants draw on existing literacies to author identites and channel voices through interactive storytelling?
2. How did participants incorporate new computational practices into their existing literacies?

Methods

This methods section builds on Chapter 3, where I report methods and context for the dissertation as a whole. Figure 5.1 shows the subset of Figure 3.5 from Chapter 3 which pertain to this research question.

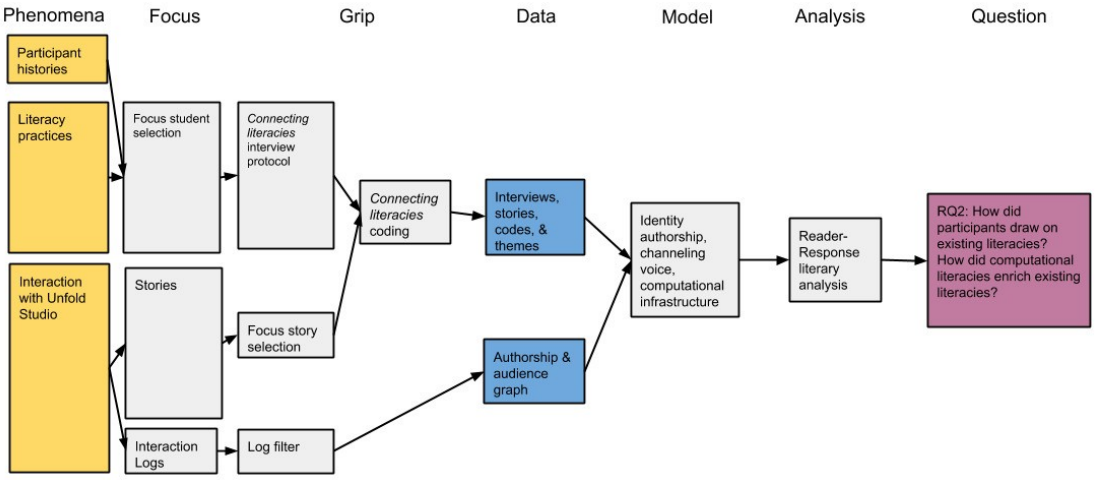

Figure 5.1: Overview of methods for RQ2

Focus

I began the process of choosing focus students in the second week of the study, after students had returned assent and consent forms and completed the pre-unit survey. I defined conditions for eligibility, and then heuristics to guide my selection. The eligibility criteria were that the student had returned assent and consent forms and consented to being recorded, that the student had completed the background/demographics survey, and that the student has generated a substantial number of stories within the first few weeks of the unit.

I selected an initial cohort of six focus students, with the intention of narrowing my focus to two while allowing for the possibility that a focus student might become unable or uninterested in participating. I aimed for an initial cohort of one student from each of the six sections (t is logistically easier to focus on one student at a time while conducting fieldnotes), and which was diverse with respect to gender, race, and prior interest and experience with computer science and parent education levels. I selected

individual students based on their answers to the introductory survey, prioritizing students who seemed to be bringing their worlds and their identities into their work, students who were exploring more complex computational concepts in their stories, and also students who appeared to be generally strong students, but who show little interest in interactive storytelling.

The original cohort of six focus students was narrowed down to three by logistical issues such as attendance and availability for interviews. I selected two focus students, Rasputin and Eragon (pseudonyms chosen by the students), who satisfy the first two priorities listed above. For contrast, I selected a third student, Collins, who was an active participant but who did not engage in the critical practices which are the focus of this chapter.

Once I had developed an initial interpretation of each student's stories and interviews through an initial round of coding (described below) I focused in on two specific stories for each student and conducted a second round of coding. In selecting focus stories, my priorities were those which were discussed by students in interviews, those which students put the most work into (based on story length and number of edits (see below), those which had the greatest readership (see below), and hose which illustrate important phenomena, as identified through the first round of coding. While it was not a criterion for selection, each of the three stories analyzed in detail below was submitted as part of the summative portfolio for the unit. The summative portfolio asked students to submit one story showing their technical skills and one story showing their

storytelling skills. Eragon's focus story was submitted as his technical skills story; Rasputin's and Collins's stories were submitted as their storytelling skills stories.

Grip

My initial goal was to compile an account of each focus student's meaning-making during the course of the unit. As much as possible, I wanted to tell the story of what the student was reading and writing, who was reading and responding to their work, and what ideas they were each bringing into their interactive stories. Once I had this account, I would be able to analyze how each student navigated the classroom literacy place and their other out-of-school literacies, particularly how they authored identities and channeled voice.

In order to analyze how authors connect across literacies, and how these connections provide resources for critical action via identity authorship and channeling voice, claims about authorial intent are needed. For example, a story set in the fictional world of a horror podcast which explores the queer identities of its characters (described below in analyzing Rasputin's stories) could be a powerful example of an author importing an existing genre and subject positions with more possibilities for identity authorship into the classroom literacy place. But such a claim would be substantially strengthened by knowing the author's perceived relationship to the horror podcast and to the classroom or school, and what they hoped to achieve by writing such a story. It would be even better to have an account of what happened when the author shared the story, the reactions of peers after reading it, and whether it had the hoped-for effect.

Therefore, I conducted a sequence of three semi-structured interviews with each of the two primary focus students. In the first interview, which took place about halfway through the unit, I asked the student to give me a tour of the stories they had written so far, which peer stories they were reading and inspired by, and their intentions for future stories. We sat together next to the student's computer so they could show me their stories. In the second interview, I zoomed in on a single story and asked the student to tell me about the story in detail. I asked about the student's motivations for writing the story, the source material and inspirations, the writing process, future plans for the story, and about who the student shared or discussed the story with. Again, we conducted these interviews in person, sitting side-by-side in front of a computer so that we could use the story's source code and runtime environment as an artifact to ground conversation. The final interview was a retrospective reflection on the unit after it had ended, which took place over video conference because I was no longer physically located at the study site. Across the three interviews, I spoke with each focus student for two to two and a half hours. These interviews were recorded and transcribed; protocols are included in Appendix X.

I used QC to code each focus student's corpus of stories as well as the three interviews about their writing. I began with a grounded theory open coding approach (Charmaz, 1996) to code the source code of both focus students' stories as well as the interviews, though I was guided by the reader-response analytical approach discussed above. My strategy was to move in an ever-tightening spiral, getting a sense of the broader context of each focus student's practices before going deeper into particular

texts. I conducted an initial round of coding on text of code of all three focus students' stories, as well as the interviews with the two primary focus stories. As I coded, I wrote frequent memos. After completing the initial round of coding, I reorganized and focused the codebook around phenomena and practices which felt important in the context of the broader conceptual framework. Although there was some overlap in corpora with the coding conducted in Chapter 4, this coding process was distinct.

Data

The primary data consisted of codes, memos, and coded texts through which I had begun to develop an account of how the focus stories worked, what they meant to their authors and their readers, and how these stories represented their authors making connections to existing literacies. I used an additional data source to supplement claims about how authors wrote stories and how they were received by audiences: data about readers' behavior. I used the authorship and audience graph to extract data about the position of the focus story within its author's broader literacy graph of stories and their readers. I also collected data about the choices readers made as they played through stories which allowed me to go beyond how stories offered possible readings, to concrete accounts of those readings.

Model

Because this chapter is focused on how authors crafted stories which were meaningful for them and for their readers, I required a method of analyzing the meanings of stories. To achieve this, I used an extension of reader-response literary analysis (Rosenblatt, 1968), which assumes textual meaning to be produced through transactional readings. Through

this lens, there is no single meaning to a text; rather there are as many interpretations as there are readers. Nevertheless, it is not the case that any given text potentially means anything and everything (this would make critique impossible). Reader-response analysis can be productive by analyzing the opportunities for meaning-making provided by the author. For example, a text might encourage the reader to hold certain expectations, to identify with a particular character, or, via ambiguity and lacunae, to allow the reader to ground themes and situations in familiar experiences. This approach is particularly suitable for interactive stories because the interactive affordances make explicit the reader's role in telling the story.

This approach is attractive because it is closely-aligned with the dissertation's broader conceptual framework. Within the literacy place, texts acquire figured meanings through transactions with readers. Rosneblatt emphasizes that a reading transforms both the meaning of the text and the reader, which aligns well with Fairclough's (2012) analysis of the critical potential of texts to transform subject positions and genres–the terms of engagement for future meaning-making. Interactional positioning (Wortham, 2001), or the ways positioning of in-story identities become reified in analogous positioning within the literacy place, is an important example of texts' critical potential. The resources available to authors, which they might desire to make legible within the literacy place, are their existing literacies and the identities they author within them.

Analysis

In analyzing interactive stories, I extend traditional reader-response analysis to include what Bogost (2006) calls procedural rhetoric, or the ways computational affordances are

used to influence an imagined player. (Montfort (2005) also develops an approach to rhetorical analysis of interactive fiction, though he is focused on parser-based games which accept open-ended textual input.) The focus remains on how stories are crafted to make available possible readings. When available, participants' reflections on their intentions are used to support this analysis.

Building on the reader-response analysis of how the text makes possible readings (or playings) available, a second analytical goal is to understand the author's experience of the text–not because authorial intent legitimizes a particular interpretation but because the author is one person who is likely to be affected by the text. For this second purpose, I approach the interview through bifocal lenses, taking the author's interpretation as prima facie evidence of their relationship to the text, while also conducting ethnographic interpretation, trying to understand what the text and its authorship means based on what its author says. If every encounter between text and reader/player produces a distinct reading, this is even more true for composition, with its continuous transformation through rereadings. Within the author's understanding of a story, I am able to produce an account of how they understood the story to be drawing on other literacies, and perhaps using them toward particular ends within the classroom literacy place.

In the following three sections, I introduce each focus student and then present a reader-response analysis of one of that student's focus stories. I use the argumentation strategy developed in Proctor & Blikstein (2019) and Proctor & Garcia (2020), staying close to the text and bringing in contextual information when it is helpful to explain something in the story or to justify a claim about it. Additionally, I draw on data about

the story's readership when it supports my interpretation of the story's effect. This analysis allowed me to develop a rich, multi-dimensional understanding of how and why the focus students wrote their stories, and how they affected the literacy place. Then in the discussion I summarize dynamics which have broader applicability to teaching and learning with interactive storytelling, and to literacy-based computer science more generally.

Rasputin

Rasputin identifies racially as "whiter than white". They present as female, but when asked how they think about their gender, they responded "a lizard person." In a later interview, Rasputin self-identified as non-binary. I use "they/them" pronouns as they prefer. Their responses to questions about interest, identity, and future plans to participate in computer science or writing were mostly neutral, though they did describe themself as pretty similar to a computer programmer, a lawyer, an engineer, and a hacker. In later interviews, Rasputin told me about how their mother is a single parent who works several low-paying jobs to make ends meet. Rasputin's mother strongly wants them to go to college: their mother has told them she feels she could have done more with her life if she had gone to college. Nevertheless, Rasputin is doubtful that they will go to college. A major source of tension between Rasputin and their mother is their desire to date girls, which their mother does not support.

Rasputin spends a lot of time online, both to stay connected to their school-based social group and as a participant in broader internet culture. This was an important source of material for their stories, particularly online podcasts. In later interviews, Rasputin told

me that the school provides uneven institutional support for marginalized youth, though some teachers go out of their way to provide safe spaces. I asked them whether they feel the school is safe, and they told me "It kind of depends on where you're at" (Interview 3). They frequently witness homophobia and racism from other students which was not challenged by staff (Interview 3). Nevertheless, Rasputin is part of a friend group which provides support and protection:

"[I'm in a friend group] where it's people that pretty much all of us are either neurodivergent or queer in some aspect. We got people with eating disorders where they stress eat a lot. We got anorexic kids. Pretty much like a lot of depressed kids. A lot of anxious kids. A lot of gay kids. Got a couple trans kids. We got four non-binary kids, including me. And like we all just kind of talked to each other about like, 'Oh I'm feeling really anxious.' Like we make sure the anorexic kids eat, things like that. We kind of help out the kids with the stress eating disorders when they're stressed out. Like we ask them what's wrong and then they maybe don't eat as much that lunch. Like that type of thing" (Interview 3).

Rasputin's final story, "Snegurochka," retells and queers a Russian folk tale. Rasputin drew the source material from a podcast called "Myths and Legends," which they

had previously listened to, and which they reviewed while drafting this story (Interview 2). In the original story (as told on the podcast), a lonely old couple creates a girl out of snow, who then comes to life as Snegurochka. In Rasputin's version, the old couple is replaced by an old woman who "mourned her dead husband and her loneliness of being

the only surviving family member," and when the girl comes to life she "ha[s] the widow's husband's gentle face, the widow's thin and small figure, and a dress as blue as ice" ("Snegurochka," line 7). These choices are the beginning of a repurposing of the source material to more directly explore gender and sexual identity.

Rasputin positions the player as an omniscient co-narrator, not as a character in the story. The player chooses which version of the story should unfold. The first choice comes as Snegurochka knocks on the old woman's door for the first time. The old woman may choose to welcome the girl in or turn her away. If the player chooses to welcome the girl in, the widow offers her tea and "by the end of the day the little snow girl had a name, a home, and a mother" (line 17). The story continues. If, however, the player turns the girl away, the girl's heart cracks, her snow body melts in the forest, and the story ends. This is an example of the "dead end" rhetorical strategy analyzed in Chapter 4, and the effect here may be to increase the player's investment in the story; there is a sense that the story continues only because of the player's choice for it to continue.

```
25  ==eleven==
26  Eleven years later Snegurochka was twenty and going to college in the village. She was a
        bright and clever woman, but her icy heart limited her to only feel deep emotions of
        love and gratitude towards the widow who she lived with, along with the passing
        shadows of other emotions she couldn't recognize. She was beautiful and had a very
        small group of friends; Sveta, Peiter, and Nora. Nora was marrying the son of the
        nearby baron the following month. One day Snegurochka and her friends went to the
        fall festival in the village and Nora brought her fiance. As soon as the unfaithful
        baron's son saw the beautiful Snegurochka he fell in love. He spent the entire night
        asking Nora questions about Snegurochka, and she was slowly getting more and more
        jealous of her friend. Snegurochka and Sveta were sharing borsch and smiling, and the
        baron's son was smitten. Nora was furious, and later when she and Snegurochka were
        alone at the well, she pushed her best friend into the deep well.
27  +[Savior]
28  ->savior
29  +[Death]
30  ->death
31
32  ==savior==
33  Sveta heard Snegurochka yell and came running, using the bucket rope tied on the well to
        pull Snegurochka up. In the village it was considered illegal to for women to "seduce
        another woman's husband or fiance" and Nora pressed charges against Snegurochka.
        Luckily the village judge was a fair man and saw the pain in the unfeeling snow
        woman's eyes at her ruthless friend going this far, and he dropped the charges
        against her. But the damage was done to their friendship and Nora and the baron's
        son's marriage was strained.
34  +[Questioning]
35  ->quest
36
37
38  ==death==
39  Snegurochka wasn't heard by anyone, and died in the well. Nora was convicted of murder
        when the melting corpse of Snegurochka was found in the well and they figured out
        that she was the last person to be near Snegurochka. Later, the baron's son committed
        suicide out of shame and heartbreak.->DONE
40
```

Figure 5.2: Lines 25-40 from Rasputin's "Snegurochka"

There are two more important choices in the story; the first is shown in Figure 5.2. Snegurochka is now twenty years old, a bright student enrolled in the local college. Limited by her icy heart, the only emotion she can feel is filial love for her adopted mother, as well as "passing shadows of other emotions she couldn't recognize." While the choice of a third-person point of view may initially limit the player's immersion in the story (as opposed to playing as a character), the tradeoff is the possibility of dramatic irony, or a gap between what the character understands and what the player understands. The player's distance from Snegurochka allows for emotional ambiguity which creates

suspense and makes room for the reader to fill in the blanks with whatever emotional situation feels most salient. Additionally, as noted in Proctor & Garcia (2020), ambiguity can create helpful distance from the content of the story and its author's identity within the literacy place, particularly when there are autobiographical elements.

The next choice comes as Snegurochka's friend's unfaithful fiance flirts with her, leading her jealous friend to push her down a well. The player may choose to have another friend, Sveta, rescue her, or for her to die alone in the well. If Snegurochka is rescued, she faces prosecution by a male judge for seducing another woman's fiance but is acquitted. If she is left alone in the well, the story ends. The player's choice comes in the context of many layers of gendered power: the fiance's heedless flirtation with Snegurochka, the friend's sexual jealousy, the law framed and administered through male power. At the center is the scene which stoked the fiance's initial interest, which notably excludes masculinity: "Snegurochka and Sveta were sharing borsch and smiling, and the baron's son was smitten." Within this context, the player's choice amounts to a decision on whether this will be a story set within a world of justice or injustice. As a player, it can be interesting to make the perverse choice to have the protagonist die a lonely death in the well (particularly as a way of exploring the boundaries of a world), but choosing the hopeful future is ultimately the only way to access the rest of the story.

```
41  ==quest==
42  Snegurochka started questioning why she couldn't feel true emotions. One day the Spring
        Spirit decided to pay a visit. She explained that since Jack Frost was technically
        her father, she could only truly love once before melting, as she was such a low
        grade Snow Sprite.
43  Snegurochka decided that she would die that day.
44  +[The True Love]
45  ->sveta
46  +[The guy that was there]
47  ->baron
48
49
50  ==sveta==
51  Snegurochka looked for her friend Sveta. Sveta was the first villager to talk to her, she
        was the first one that wasn't scared of her, she was the one who saved her from the
        well. Sveta was the first besides the widow, to love her. Snegurochka ran across the
        village. Sveta saw her, and ran to her. They hugged. As the Snow Maiden who could
        love laughed, she started to melt. It was gradual, but within five minutes she was
        half melted.
52  Her last words were "I love you, Sveta."
53  ->DONE
54
55  ==baron==
56  Snegurochka looked and saw the baron's son. He was still infatuated with her. She ran
        over to him, hugged him, and melted. He was there, he "loved" her, he was convenient.
        She got to feel love in at least some form before her end. Even if it wasn't true.
57  ->DONE
```

Figure 5.3: Lines 41-57 from Rasputin's "Snegurochka"

When the player continues, the story reaches its crux. Snegurochka learns that because she is made of ice, feeling love will warm her and cost her her life. "Snegurochka decided she would die that day," and the player must choose between the "True Love" or the baron's son, "the guy that was there" as the object of love. Beyond presenting the option for same-sex attraction (not present in the source material), Rasputin glosses the choices, suggesting that choosing the baron's son would be a pragmatic and socially safe way to "feel love in at least some form … even if it wasn't true." In this final choice, the story positions the player's point of view closer to Snegurochka. In previous choices, the player made plot choices about other characters' behavior; here the player chooses how Snegurochka responds to her "passing shadows of other emotions." The player does not choose Snegoruchka's true feelings, only how she

acts on them, or perhaps the extent to which she chooses to recognize them. Because the player has been drawn so close to Snegurochka's point of view, the story creates the opportunity for the player to ask the same questions of their own life. This is a subtle form of interactional positioning. The story creates the opportunity for an association between the identity authored by the player in-game and the player's identity in the literacy place; exploring possible identities in the former could make space for similar exploration in the latter.

Generally, reader-response criticism cannot go beyond hypotheses about how a reader *might* engage a text. Because some of the interpretive work is moved out of the reader's mind into the interactive affordances on the screen, we can go a bit further and examine the choices readers actually made as they played a story. These choices are shown in Figure 5.4, where the number on each edge counts the number of play-throughs traversed it. While this data cannot reveal why readers made certain choices or how they understood them, they can at least establish which parts of the stord readers tended to explore. For example, while a roughly equal number of readings chose to have Snegurochka fall in love with Sveta and with the baron's son, few readers chose to let Snegurochka die in the well. Most of the readings occurred in repeated sessions, with a reader exploring multiple possible endings.

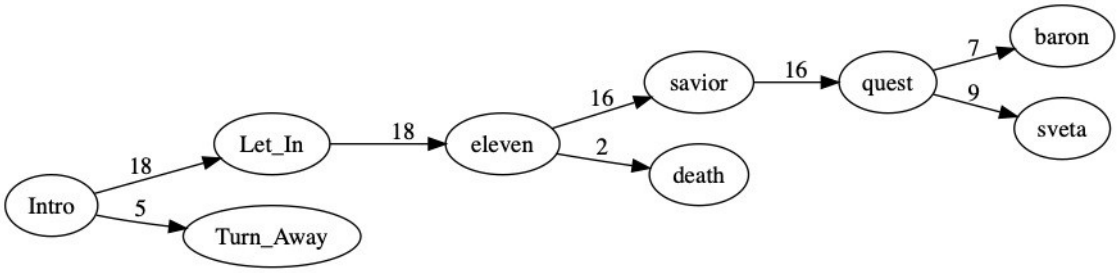

Figure 5.4: Graph of readings of "Snegurochka"

In our final interview, I asked Rasputin about their authorial intentions. Rasputin was intentional in adapting the source material to include same-sex attraction, but their explanation of this choice was not based on a desire to increase visibility of marginalized sexual identities. When asked how they changed the source material, they said:

> [In the original story] she had been falling in love with another boy and her friend and I changed it to another girl, just to make it a bit more believable that she felt kind of isolated from everybody else in the Russian village. So I was kind of using it as a symbolism and also just for fun because I've always known that Sveta is a Russian name but I've never been able to use. (Interview 3)

Instead of using the story to comment on or try to change the world, Rasputin's initial concern is with making the story more believable. Rasputin's association of sexual marginalization with isolation and loneliness leads them to recognize these experiences as plausible in Snegurochka, and useful to the story's coherence.

Rasputin's adaptation of the folktale takes place within the context of a podcast whose host positions himself as an irreverent commentator on historical stories–a distinctive speech genre. Rasputin adopted this speech genre in their own writing, saying, "I agreed with the guy that runs the podcast. [The original version of Snegurochka] didn't have that great of an ending. Like it was kind of a lazy ending almost" (Interview 3). This

is quite different from traditional school-based way of teaching mythology, which might encourage moral interpretation of characters within folktales or to retell them as modern adaptations, but not to critique their validity or value as folklore or as narrative. While there are contexts in which critiquing the narrative quality of folklore could be damaging, this speech genre was useful to Rasputin.

This was not the only instance of Rasputin adopting genres and speech genres from their online communities. They discussed their extensive involvement with queer horror podcasts and games, and wrote several stories in that genre. Additionally, Rasputin wrote several stories in a distinctive voice familiar from a particular community of confessional YouTube videos. These stories are raw and vulnerable, and very explicitly address the audience as a supportive, knowing community. Memes are used to index ideas the audience is presumed to be familiar with as a way of establishing intimacy. Like the speech genre of critiquing folklore, Rasputin's channeling voices from online communities of horror podcasts and confessional YouTube channels provided them valuable tools for opening new possibilities for identity and expression in the literacy place.

Even though Rasputin explained their inclusion of same-sex attraction in "Snegurochka" in terms of improving the story's narrative coherence, they were definitely aware of its critical significance and readers' possible reactions. When I asked them what they wanted the reader to experience while playing the end of the story, they said they wanted the choice to be "romantically symbolic…because you see people that break up with somebody and then they just kind of decide that dating is really hard and

go back to them even though they're obviously bad for them. Or you can have the person that actually loves you and respects you" (Interview 3). Again, Rasputin explains an authorial decision in terms of improving the story, but their answer also suggests that crafting the character of Snegurochka had personal significance and was also intended to be an opportunity for the player to consider this emotional situation. Raspitin repeatedly emphasized that they understood their writing as "sprinkling" lived experiences into fictional narratives from various sources.

Following up, I asked Rasputin how a player who had not thought much about sexuality might experience the choice to have Snegurochka fall in love with Sveta. Rasputin replied, "It takes a lot of consideration in my story to make the gay characters. Because I feel like in normal media it seems like people try too hard. Like [Lando Calrissian] in Star Wars. They said he was pansexual. Even though it would not have anything to do with any of the movie" (Interview 3). Rasputin understood the Star Wars writers' revelation that Lando Calrissian is pansexual as clumsy pandering, a superficial attempt to satisfy LGBTQ audiences' desire for representation and inclusion, or perhaps even more to appear to be doing so for the real audience of straight progressives, who value the inclusion of diversity, positioned in a particular way. In contrast, Rasputin wanted to include queer characters and experiences who were not marked as such: "Like if you don't pay attention to the Snegurochka story you might go, 'Oh, she's falling in love with Sveta.' You won't actively be at the spot of, 'Oh, she's gay'" (Interview 3). Rasputin's concern for the positioning of queerness, as well as their deflection of my

question about how a straight reader might experience the story, resonate with Morrison's positioning with regard to the "white gaze."

> I didn't have to be consumed by, or concerned by, the white gaze. That was the liberation for me. It has nothing to do with who reads the books– everyone, I hope… but my sovereignty and my authority as a racialized person had to be struck immediately with the very first book. And it was strange because in this country, many books, particularly then, 40's, 50's, you could feel the address of the narrator over my shoulder, talking to somebody else. Talking to somebody white. I could tell because they were explaining things that they didn't have to explain if they were talking to me. (Morrison, 1998)

In the language of this dissertation's theoretical framework, the white gaze (or here, the straight gaze) can be understood as a presumed audience in a privileged position, expecting to be addressed in a particular voice. The critical work in "Snegurochka" may not in fact be educating those who unconsciously enact the straight gaze, but instead carving out space for authors and audiences by channeling other voices which make different identities addressable. Rasputin did not import subject positions into the classroom literacy space directly (as might have been the case if "Snegurochka" contained a strident call for the legitimacy of same-sex attraction). Instead, Rasputin imported (particularly from the world of queer horror podcasts and confessional YouTube addresses) a dialogic voice which figures speaker and audience by making clear what is already familiar and therefore does not need to be explained.

Rasputin's account of the story's readership supports this interpretation. They told me that while several peers had added the story to books of stories they liked, Rasputin had not discussed the story's contents with friends: "I do know if they have [read the story] they just didn't tell me that they liked the whole Sveta and snow maiden thing just

because, you know, representation. All of us feel kind of nuts when we find out what a character we really like was actually gay the whole time. Just because it makes it a bit more relatable" (Interview 3). (Rasputin's inflection in the interview made clear that "all of us feel kind of nuts" connotes enthusiasm, not confusion or frustration.) Here, Rasputin makes clear that while representation is important to them and their community, the fact of marginalized identities being included is not enough. The mode in which representation is marked or figured is crucial; the inclusion of "diversity" within the discourse of the straight/white gaze can feel bittersweet. This is delicate work which can probably only be achieved by an active participant in the literacy place.

Eragon

Rasputin's case study focused on how connecting across literacies can support criticality by channeling voices and making subject positions addressable. The next case study centers the role of computational infrastructure in connecting literacies. Computational infrastructure was not the focus of Rasputin's case study, but the infrastructure of their literacy practices–YouTube, podcasts, interactive storytelling on Unfold Studio–played an important role in supporting these literacy practices and connections across them as well.

Eragon identifies as male, and identifies racially as "All over Africa and Arab countries." He is an immigrant from Lebanon, and speaks fluent Arabic as well as English. On the pre-survey, he wrote his name in English and in Arabic. At the beginning of the unit, Eragon reported high interest in studying writing and computer science, and participation in extracurricular activities related to both computer science and writing. He

had some prior exposure to the Java programming language, but "I didn't get very far into it at all, I'm a lot better at Ink than I am with Java. But it kind of set the background" (Interview 3). Eragon said he would probably become a computer scientist or engineer of some sort, and would definitely also become a writer. One of his parents is an engineer.

Despite this strong interest and self-image as a possible future computer scientist, Eragon has little access to learning ecologies that could sustain interest and identity development. In the pre-unit survey, he said his friends were not very interested in computer science or writing, and that he did not have adult mentors in either field. Through our later interactions, I got the sense that he was lonely and that he felt he did not fit in well to his school. The study took place during Ramadan, and Eragon chose to stay in the computer science classroom during lunch whenever possible because his peers did not understand the context of his fasting. When, in later interviews, I asked Eragon about whether he shared his interactive stories with his family, he told me he doesn't talk with them about school things, and quickly diverted the conversation. Eragon and I developed a strong rapport during our lunchtime conversations, which were frequently driven by his relentless curiosity about technology. Midway through the unit, he submitted a short, private, and unsolicited story titled "my grief ":

> People are so mean. Why don't they understand how they make people feel. My thing to change in the world is that if you hurt someone without a very justifiable reason, you are forced to feel twice as bad. I was a very social person, but the evil human beings around me have changed that. I may have survived my grief in Ermine Elementary, but…

Eragon was a prolific participant in the interactive storytelling unit. His final story, "Lemon Trees," was the product of weeks of work, including several other stories which

served as prototypes. “Lemon Trees” is patterned on a story we played midway through the unit called “A Dark Room” (Doublespeak Games, 2013) to explore the idea of state. “A Dark Room” is described by its developer as a “minimalist text adventure,” and was identified by several students as belonging to the “grinder” genre because the game is essentially a never-ending accumulation of resources.

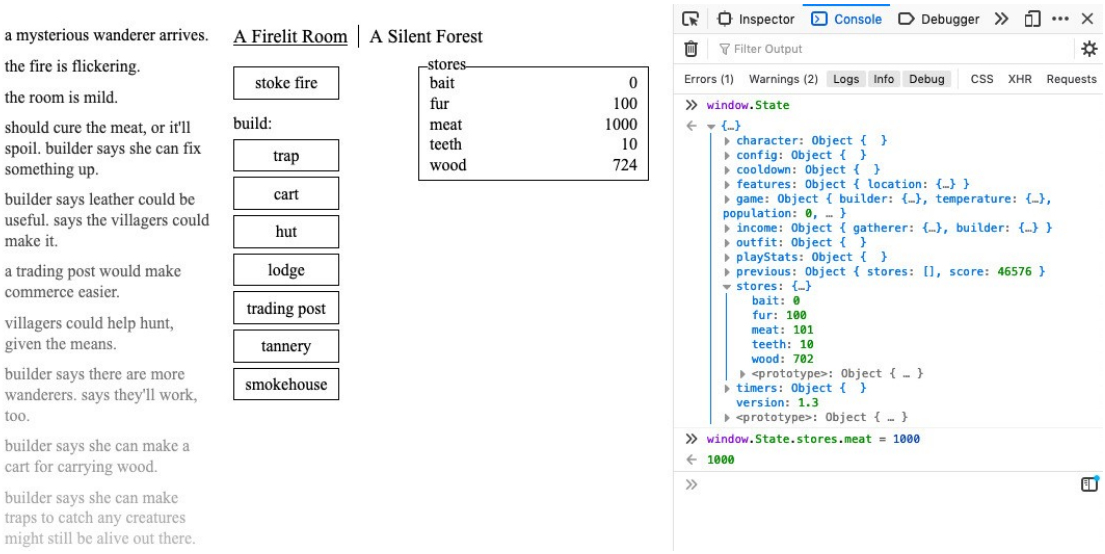

Figure 5.5: Screen shot from “A Dark Room,” with the javascript console open on the right

Because the interface is so simple, “A Dark Room” served as an excellent example of how a game can be built around state. There is very little to do in the game except gather resources and exchange them for other resources, which gradually accelerate the process. Building a cart speeds up wood collection; building a tannery allows the conversion of wood and meat into leather, and so on. Every player action results in a clearly-visible change to the game state. Even better, the game is written in unobfuscated javascript, so the player can easily open the web browser’s developer

console to explore and manipulate `window.State`. Figure 5.5 shows a screenshot of "A Dark Room," with inspection and manipulation of the game state via the javascript console on the right. Changing `window.State` so that the player has millions of resources turned out to be highly entertaining activity for the class, and several students (including Eragon's story) went on to write games in the same genre.

"Lemon Trees" adapts the grinder genre to Eragon's own scientific interests, allowing the player to cultivate lemon trees and collect objects such as galvanized nails in order to create a lemon battery and ultimately discover electricity. "Lemon Trees" also incorporates elements of the role-playing game genre, as the player can collect armor and weapons to more effectively fight monsters.

```
1  INCLUDE 6766
2  INCLUDE 8725
3
4  //                                        THE EXPLANATION.
5  // In this game you start getting money by lemon trees and eventually you can get galvanized nails and copper
6  // which you use to make lemon electricity infused into weapons OR you discover electricity and make a bunch
7  // of money which helps you later in the game. You will be able to fight and maybe get apple trees which you
8  // don't sell apples from because you use the apples to stay alive and you can have water which would be heavy
9  // and slow you down but it lets you explore further into my world. I will add stuff even after
10 // the exam thing is done.
11
12 //                                     RANDOM THINGS THINGS TO KNOW
13
14 // ABOUT
15 // sword can be made sharp later which does more damage. damage is random mainly but steel swords and sharp
16 // steel swords would most of the time do a lot more damagethan a wooden sword but technically there is a
17 // chance that a wooden sword does more.
18 // bow is long ranged and so in battle unless something snuck up on you or thye also have something long
19 // ranged you can already attack them while they are going towards you.
20 // chainmail. chainmail is very common compared to plate and protects you a certain amount from different
21 // weapons.
22 // plate armor. plate is supreme and has chain mail under some joints to get maximum mobility. plate is very
23 // rare and/or just expensive.
```

Figure 5.6: Lines 1-23 from Eragon's "Lemon Trees"

One notable aspect of "Lemon Trees" is that the game is structured to invite the player to read the source code while playing. (This is supported by Unfold Studio's option to support a side-by-side view of source code and program execution.) The introduction to the game, shown in Figure 5.6, is not shown during program execution,

but is instead included as comments in the source code. These comments serve as an instruction manual and as a tutorial explaining the game's structure. Eragon adopted this mode of play from the activity with "A Dark Room" in which we played the game while also interacting with its source code. By writing a game intended to be simultaneously played and inspected, Eragon created an opportunity to author an identity for himself as a friendly, knowledgeable advocate for science and computer science. Just as the introductory comments shown in Figure 5.6 explain the game's mechanics, Eragon created other stories in the genre of online tutorials with names such as "WHY U SHOULD USE VARIABLES" and "HOW TO CHANGE FONT COLOR!!!"

Eragon drew on his existing literacies in his stories, as well as frequently drawing inspiration from other stories on Unfold Studio. However, in contrast to Rasputin, Eragon more often adopted functional or structural features of other texts for his stories. He was prolific in forking stories I wrote to demonstrate techniques, as well as using the `INCLUDE` directive to import parts of other stories directly into his. For example, line 1 (Figure 5.6) includes a story I wrote which defines several helper functions related to probability. Eragon uses the `chance` function on line 74 (Figure 5.7) to define the probability with which one of two possible events should take place. Eragon learned to incorporate HTML into his stories from a story written by students at another school, and, recognizing that both Unfold Studio stories and "A Dark Room" run in a javascript environment, he made several attempts to inject javascript into his stories.

```
59  //                                                  THE LEMON SECTION
60  ===lemonseeds===
61  + [grow them?]
62  ->lemongrow
63  + [go back to start page]
64  ->start
65  + [search again]
66  ->search
67  ->DONE
68  ===lemongrow===
69  {lemongrow >=10: -> alive}
70  You water the seeds after planting them in a nice spot. Make sure to come back here often so they get watered.
71  + [go back to start]
72
73  ===alive===
74  {chance(50):One tree survives ~ lemontree += 1|Two trees survive ~ lemontree += 2 }
75   Grown lemon trees can live longer without water so they can survive with just rain. You have {lemontree} lemon trees.
76   + [go back to start]
77   ->start
78
79  ===havelemontree===
80  You now have a lemon tree!
81  + [go back to start]
82   ->start
```

Figure 5.7: Lines 59-82 from Eragon's "Lemon Trees"

The subsystem shown in Figure 5.7 implements a loop in which the player can plant lemon seeds and water them until one (or two, if the player is lucky) matures. This part of the game presents a very different experience to the player from the interiority and characterization of "Snegurochka." This game is less immersive and more interactive, perhaps not as well suited to evoking emotion or subjective experience in the player, but instead offering the ability to interact with a system and to learn what it feels like to be in the game-world Eragon has crafted, and the dominant mechanics.

The open source code, ability to fork the story and modify it, and particularly Eragon's comments addressed to the player, invite the player to engage the story as a half-baked microworld (Kynigos, 2007), "a microworld which is explicitly designed to engage its users with changing it as the main aspect of their activity" (p. 335). Even if this game does not invite an immersive reading experience, its enactment of game mechanics such as building up resources, searching for treasure, fighting monsters, and gathering the items necessary to generate electricity, allows for a kind of embodiment which Papert

(1980) believed to support powerful relationships with mathematical ideas, and which Bogost (2012) celebrates as the primary creative potential of video games.

When I asked Eragon about his intentions in writing "Lemon Trees" and his other stories, he consistently returned to a desire to shape the form of the story, and to explore how code allows new forms of narrative: "If there's a story with tons of different possibilities that interlock and weave together, that's cool to think about. That's why I like Unfold Studio. I want to be an author when I grow up, and with coding you have to think of what to do before you do it. I have to think ahead of time, what's it going to be like when I put this in?" (Interview 3) For Eragon, programming is similar to drafting prose in that he is constantly reimagining the text by considering the player's experience. In one interview, I shared that my motivation for creating Unfold Studio was to help people connect computer science to other forms of expression they already cared about. He replied, "That happened for me. Do you know why? Because I really love books, and stories, and things like that. And I really like messing around with things, changing them… It's like I'm a fictional engineer" (Interview 2).

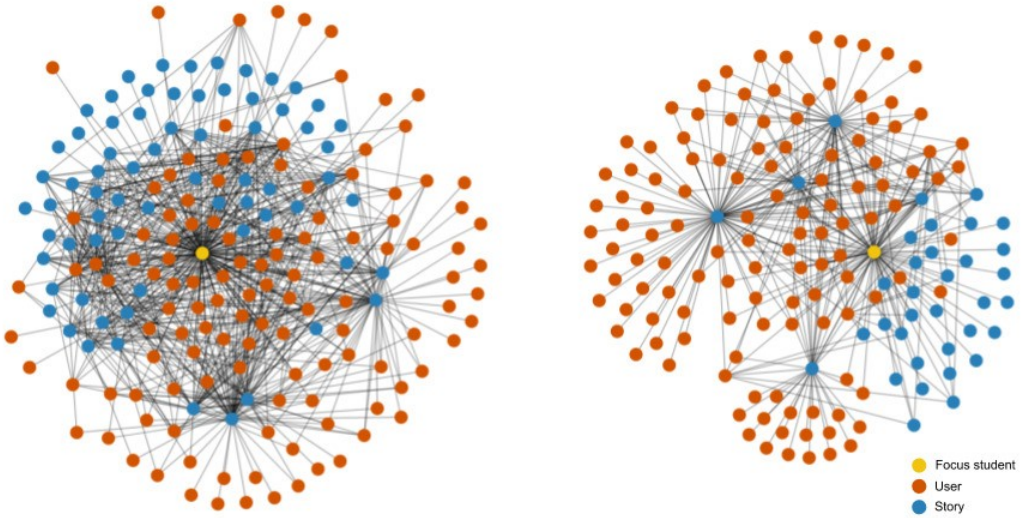

Figure 5.8: Literacy networks of Rasputin (left) and Eragon (right). Links between nodes represent interactions between users and stories; tighter links represent more interaction.

"Fictional engineering" was not an individual pursuit for Eragon. In the classroom, he collaborated with several peers on stories and he told me that he frequently talked about his writing with friends after school on the bus ride home. If Eragon often feels lonely and out of place at school (as suggested by his survey responses, my fieldnotes, and our interviews) the opportunity to author an identity as a knowledgeable guide was likely important to him socially and as a catalyst for developing his expertise. Figure 5.8 shows the literacy network of Rasputin and Eragon, plotting each focus student in the center, and including all their stories and all users who interacted with them (by following them) or with their stories (by reading, loving, or forking them). Whereas Rasputin has a dense network of stories and readers, Eragon's network has fewer links and his connection to most other users is mediated by a few stories which gained a wide readership. "Lemon Trees" was one of these widely-read stories. It was played 105 times

during the unit and was for a time the top story on the homepage (stories are weighted by freshness and popularity).

The authorial identity through which Eragon was able to gain a readership was embedded in the infrastructure of Unfold Studio, and he took a keen interest in how it worked. He repeatedly asked me about the algorithm by which stories moved to the front page of Unfold Studio, and conducted experiments with friends to game the system by forking a story many times or exhorting readers to love stories in a manner similar to YouTube vloggers. In another interview, he asked me to add a view of a user's social network to the profile page.

His interest in how the infrastructure works was consistently motivated by interest in how the infrastructure shapes practice. Often, Eragon wanted to understand the infrastructure so that he could extend the possibilities of his stories. This was the case with his experiments in injecting HTML and javascript, where he tried to adapt techniques from "A Dark Room" to his own stories. He frequently tried to incorporate familiar elements from other digital interfaces into his stories. In the conversation below, Eragon asks for help implementing a search bar into his story.

> Eragon: There's one thing you need to be able to do. That's the search bar thing.
> Chris: In the story or in Unfold Studio?
> Eragon: In the story. Look at this. How do I look at the code for the actual search bar?
> Chris: You get presented with a page that's built out of HTML. But Google has a computer on the back that builds that page and sends it to you. You can't necessarily see that.
> Eragon: So I cannot see how they made the search bar?
> Chris: You can see the search bar, but you can't see what happens when you send it in.

> Eragon: Is that so they have less competition, so that [competitors] have to figure it out for themselves?
> Chris: Yeah, and because they don't want some mischevious person to mess up Google. There are people who get paid thousands of dollars to get your search results higher–it's called search engine optimization… It's kind of like in Unfold Studio, if people started getting competitive to try to get the top story on the homepage.
> Eragon: Then they could make another account. (Interview 2)

Eragon's desire to add a search bar to his story leads to an investigation into which parts of Google's search service can be accessed by a user and which are inaccessible. Eragon uses search bars all the time, so it was natural that he would want to add one to his story, just as other authors added emoji and text messages (discussed in Chapter 4). But he had not thought deeply about how a search bar might work. By positioning himself as an author attempting to appropriate interface features, he was able to access learning opportunities in this everyday computational infrastructure. The pattern of beginning inquiry from a purpose situated in the literacy place occurred over and over. For example, once Eragon had become comfortable using variables in his stories he tried to figure out how story state could be shared across players to enable multiplayer stories. When I asked Eragon about experience with different programming languages, he again stressed that what was most important was the contexts of their use: "I was trying to learn Java for robotics but Khan Academy just showed me Java for drawing" (Interview 3).

The examples above show how the position of being an author writing for an audience created opportunities for Eragon to develop interest in computer science. However, developing an understanding of the infrastructure supporting literacy practices (individual stories running in javascript and the literacy community running in Unfold Studio) also provided conceptual resources. Eragon's growing understanding of how

variables enact game state provided him a representational medium for asking philosophical questions: "So this is the second story I made, and it's about three people who wake up and it's like they're looking at themselves, and the only reason they have different thoughts is because they have different variables. They're test subjects, they're the same person three times" (Interview 2). Here, he is able to use the idea of state to write a story exploring what makes us unique.

Collins

One final student serves as a counterpoint to the first two. Collins's experience with interactive storytelling had some similarities to Rasputin's and Eragon's, but also some important differences. He presents as a white male (he chose not to answer demographic questions about his racial and gender identification) who indicated on the pre-unit survey that he would definitely not become a writer or a computer scientist, nor was he interested in future coursework or clubs in these areas (though he finds computers interesting). Both of his parents have graduate degrees and work in STEM fields, and, as his stories make clear, his family has a high socioeconomic status.

```
29  ==Security==
30  You begin the wait for the the line when you realize there is a seperate line for Economy
        Plus which is what your ticket says.
31  +Head over to the Economy Plus Line
32  ->Line
33  +Stay in current Line
34  ->CurrentLine
35
36  ==CurrentLine==
37  You stay in the current line and by the time you get through Security and get to your gate
        the plane has left. You get a make up ticket, but lose your Economy Plus Seat, and you
        regret it forever.
38
39  +DONE
40  ->DONE
41  +Replay
42
43  ->Airport
44
45  ==Line==
46  You go th the Economy Plus Line and get through it quickly. You have 1 Hour left before
        boarding starts at
47  7:50 A.M., and thanks to your great thinking.
48
49  +Go check in Bag
50  ->Bag
51
52  ==Bag==
53  You go to check in your { ~ 2|3 }  Bags, but realize it is less than the required carry on
        bag so you could save some money without paying for a Baggage fee.
54
55  +Take your bag as a carry on
56  ->CarryOn
57  +Or pay for it, so you don't have to carry it on.
58  ->Pay
```

Figure 5.9: Lines 29-58 from Collins's story, "Business Trip"

I became interested in Collins's writing because almost every story was about airplanes, airports, or vacations involving air travel. Figure 5.9 is a typical example. The player inhabits the identity of a business traveler and the goal is to successfully and comfortably navigate the journey. In this excerpt, "You begin the wait for the line when you realize there is a seperate line for Economy Plus which is what your ticket says." If the player chooses to stay in the line with the regular passengers, he misses the flight, is given a replacement ticket which does not have Economy Plus status, and "you regret it forever." The game ends and offers to restart. If, on the other hand, the player uses the

Economy Plus line, he moves quickly through security and has an hour free before the flight "thanks to your great thinking."

As the story continues, the player must navigate a series of such scenarios; when the player makes a wrong decision the game reaches a dead-end, the player is chided, and is presented with an offer to start again. For example, when boarding the plane the player should greet the flight attendants so that they like him and upgrade him to first class. Otherwise, "You arrive at your seat and have a great flight" and the story ends. The player has to know that another level of privilege is available. However, it is also important to know when to stop. When the player arrives at his first-class seat, if he chooses to complain about the food, the situation will devolve into his being kicked off the airplane. The story continues, sometimes requiring the player to make the right choice, and other times painting a detailed picture of luxury travel: "Inside the Delta Premium Plus Amenity Kit, you find a Tumi-branded eye mask, earplugs, disposable socks, a pen, tissues, a dental kit, mouthwash, hand sanitizer and Kiehl's lip balm."

"Business Trip" is skillfully-written, making substantial use of literary and computational affordances to produce a coherent rhetorical effect. The story provides the reader a glimpse into the world of first-class air travel, turning the codes of the culture of power (Delpit, 1988) into a game or an examination to see whether the player can pass the tests. At the same time, Collins authors an in-game identity for himself as a host and occasional commentator on the player's success in passing in the world of first-class travel. In the fact that he knows all the right details, Collins implicitly demonstrates that he has access to this world in real life.

In the context of the classroom-based literacy place, where most of his readers have probably never been on an airplane, this game enacts a powerful form of interactional positioning. The relationship between the player and the in-game narrator shapes the potential relationships between the reader and author in the literacy space. The author repeatedly positioned himself as high social class, having insider knowledge of airports, airplanes, and the aviation industry. The player gets to live out the fantasy of buying airplanes and starting an airline, but the experience created for the player does not feel entirely generous.

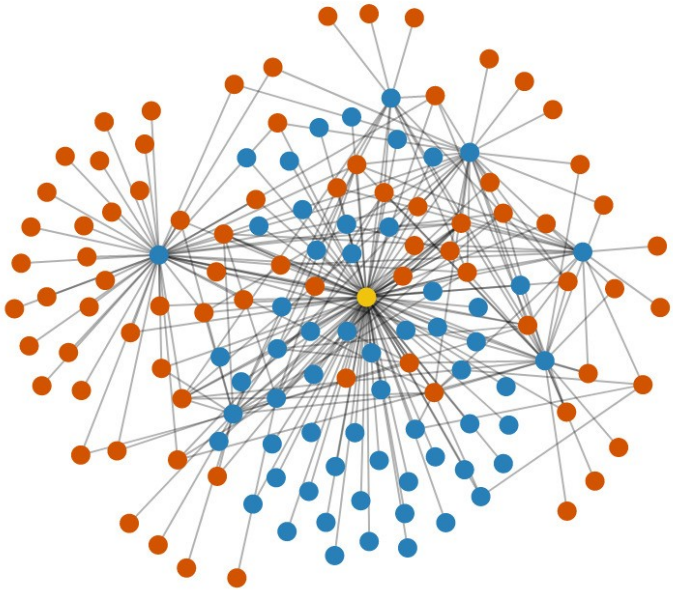

Figure 5.10: Collins's literacy network. "Business trip" is the leftmost blue dot, connecting many other readers. Links between nodes represent interactions between users and stories; tighter links represent more interaction.

"Business Trip" is an example of Collins connecting across literacies to author an identity which probably feels authentic and important, and which provided the context for learning opportunities and possibly interest in future computer science learning. He may have understood sharing this story to have been an act of generosity, sharing part of himself and his experiences that his peers may never have experienced. And yet I am skeptical that writing the story involved personal growth for Collins or an enjoyable playing experience for many of his peers. "Business Trip" represents critical action in the sense that there is an awareness of how narrative can reconfigure subject positions and forms of expression, but the ends to which it is deployed are quite different than in "Snegurochka." I read "Business Trip" as a transformation of cultural capital (existing high-status literacies) into a form of identity or positional capital whose payoff is social prestige and learning opportunities. Figure 5.10 offers one way of visualizing this payoff. Amidst his modest network of stories and readers, "Business Trip" is the story on the far left, Collins's most-read story and the node which moves him into a more central position within the literacy network. In concrete terms, this central position meant more visibility for Collins, potentially higher social status, and access to more learning opportunities.

Discussion

In the background to this chapter, I proposed grounding computer science education in emergent literacy places built from existing literacies. I then asked whether this would be a responsible way to teach computer science. Certainly, it is hard to square with computer science viewed as a branch of engineering, where the priorities are (rightly) correctness, robustness, safety, and efficiency. However, this more specialized definition is more

suitable for advanced coursework, and I believe it can happily coexist with a literacy-based approach to computer science, particularly at the introductory level. I have argued throughout this dissertation against having a single definition of computer science. Rasputin's and Eragon's case studies illustrated how a literacy-based approach to computer science could support youth in critical identity authorship and channeling voices, in the classroom literacy place and in their multiplicities of informal digitally-mediated literacies. Centering equitable inclusion, and critical inquiry into the conditions of inclusion, is particularly urgent in K12 education, where futures are more profoundly foreclosed through denial of learning opportunities.

Eragon's case study in particular illustrates the role of common infrastructural media in connecting literacies. Eragon repeatedly noticed common infrastructure (html, javascript, frontend/backend structure) and drew on computational concepts such as variables and state to bring practices across contexts. Unfold Studio presents source code and runtime environment side-by-side, so that a player can efficiently consider all possible branches of a story by reading the source. Eragon recognized the same pattern in "A Dark Room," using the developer console to explore the game's source code and manipulate its state. From here, it was only a short leap to considering the code behind other interfaces, such as Google's search engine, which are rich in computational learning opportunities but which are also sites of social and political issues which cannot be fully understood without considering their computational infrastructure. By grounding the study of computer science in existing literacies, critical engagement with genre is at the same time engagement with the computational media in which genres (or meaning-

making processes) are encoded. My claim is that when computer science is allowed to emerge as a literacy practice in dialogue with other literacies, computational ideas are bound up with social and critical meanings.

Any disciplinary pedagogy ("teaching computer science") will inevitably produce a figured world in which certain ways of being and forms of sensemaking are centered. That is the point. However, if our goal is to support critical engagement with computer science, where part of the work involves redefining the subjects positions and genres by which we understand excellence, the practical question of assessment comes up. Without externally-assigned goals and standards, how could we determine the quality (and relative improvement) of student work? Is it even possible to speak of quality in such a situation?

This chapter used an extension of reader-response literary analysis, supported by interviews with story authors, to understand the possible meanings of stories. While not typically part of reader-response analysis, I also considered the effects authors intended or hoped for. In contrast to assessment of stories using an a priori instrument such as a rubric, this approach centered youth sense-making, regardless of whether it came in an expected or conventional form. While it might seem that such an approach is more suitable for humanistic approaches to computer science than laying the foundation for an engineering or rigorous scientific discipline, applying literary analysis to computer programs builds on the tradition of "literate programming" (Fog & Klokmose, 2019; Knuth, 1984) which frames programs as artifacts for communication and collaboration between peers. Earlier proposals for "software criticism" (Papert, 1987; Pea, 1987) similarly suggested that software artifacts could be analyzed like literary texts as artifacts

of and contributors to "computer cultures." More broadly, there have been influential arguments within engineering education that assessment and instruction ought to be more oriented toward producing "competency in action" (Denning, 1992) rather than rote performance on narrowly-defined assessments. Denning draws on Sizer's (1992) competency-based education to argue that engineering curricula should aim to produce students who can think flexibly and respond to new kinds of challenges in complex, real-world contexts. (It is important to distinguish this sense of "competency" from the recent appropriation of the term to mean each student moving at her own pace in arguments for "personalized learning.") An assessment strategy which is focused on student sense-making and agency could play an important role in this agenda.

Conclusion

Through several detailed case studies of student authors and their stories, this chapter analyzed how authors connected their existing literacies to the classroom literacy place and how they used concepts from computer science to critically engage their existing literacies. This chapter showed how writing interactive stories created the context for identity authorship and channeling voices which both changed the classroom literacy place and provided learning opportunities to engage with the computational media of Ink and Unfold Studio.

RQ3: Learning CS as author and audience

Introduction

The previous two chapters analyzed the ways participants read and wrote interactive stories with Unfold Studio, starting with an analysis across all participants and then focusing closely on several case study students. These chapters traced how authors used literary and computational affordances toward rhetorical and critical ends, and how they connected their existing literacies to the classroom literacy place. One goal of these chapters was to characterize a critical computational literacy space without reference to dominant conceptions of computer science.

This chapter puts that example of critical computational literacy in dialogue with computer science as framed as an academic discipline, showing that *even on those terms*, a literacy-based introduction to computer science can be effective. The goal is not to justify or legitimize the reading and writing which took place during the interactive storytelling unit: I do not believe that is necessary. However, just as *channeling voices* in order to be heard requires a dialogic approach of working with existing genres, there is value in making the literacy-based computer science education I have been exploring legible within the existing field of K12 computer science education. Toward that end, in this chapter I develop quantitative measures of literacy participation aligned with my conceptual framework, and show that this participation is associated with better performance on a summative assessment aligned with mainstream K12 computer science education content knowledge and skills.

Background

Assessing learning in K-12 computer science

Despite its roots in Constructionism (Papert, 1980), recent Computer Science education research has been dominated by a cognitive paradigm. In practice, this means assessment of Computer Science learning has tended to assume that the nexus of learning is "the individual mind in isolation, context-free problem-solving and mental representations and reasoning" (Tenenberg & Knobelsdorf, 2014, p. 1). In this framing, assessments would ideally be validated as consistently measuring students' mastery of content regardless of context (Tew & Dorn, 2013; Tew & Guzdial, 2011). Among the minority of computer science education assessments which are validated, most have a cognitive framing (McGill, Decker, McKlin, & Haynie, 2019). This framing aligns well with the infrastructure of policy and research, as learning outcomes can be taxonomized a priori, programs built around these goals, and measures based on these outcomes can be used to compare different approaches with a common target.

Equity-oriented research, aimed at addressing computer science's legacy of stereotypes and structural barriers to participation, has in contrast often adopted sociocultural and critical framings which center students' relationships to context and the power relationships mediating their access to learning opportunities, opportunities to participate, and ability to convert learning into subsequent opportunity. These framings tend to see learning in terms of participation (Burke & Kafai, 2012), identity-building (Shaw & Kafai, 2020), and critical computational action (Tissenbaum, Sheldon, & Abelson, 2019). The empirical work in this area has shown the importance of sociocultural factors. For example, Fields, Vasudevan, & Kafai (2015) studied a

collaborative approach to support interest-driven creation of digital media through observations, interviews and programming artifacts. Çakır, Gass, Foster, & Lee (2017) investigated the impact of a game-design workshop on girls' attitudes towards computing through surveys and focus groups. Grover, Pea, & Cooper (2016), Friend (2016) and Hansen et al. (2017) examined how youth perceive computer scientists using surveys and drawings. However, when so-called non-cognitive constructs are included in empirical research, they are typically used as contextual factors influencing achievement and learning as measured by other assessments, rather than as prima facie evidence of achievement and learning (McGill et al., 2019).

This chapter uses a similar approach, analyzing the effect of sociocultural variables on a summative cognitive assessment, but it is intended as a stepping stone toward centering sociocultural framings of learning by developing several quantitative measures of learning in participation. Drawing on the conceptual framework developed in Chapter 2, particularly the dialogic understanding of identity authorship and channeling voices, in this chapter I develop audience scores and authorship scores measuring the extent to which participants interacted with other users' stories (audience) and the extent to which they wrote stories which were read by others (authorship). Rather than thinking of audience and authorship participation as two directions of information flow, I see both as active and potentially critical participation in addressing and making oneself addressable as part of a responsive audience.

Case study

This chapter's approach to analyzing the relationship between literacy participation and computer science learning emerged from qualitative observations over the course of the unit. This section presents an account of one student's learning over the course of the unit. This account motivates the chapter's research questions, as they essentially explore the extent to which the dynamics contributing to this student's success generalizes to all participants.

Zdev (a pseudonym chosen by the student) is a 12-year-old white male with no prior experience with computer science or related activities such as creating games, art, websites, or computer programs or participating in robotics or maker clubs. He also reported very little prior participation in literacy activities such as journaling, writing fiction, or book clubs. Zdev described himself as "not very similar" or "not at all similar" to all the computer science- or literacy- related professions listed. (See the subsection on surveys in Chapter 3 for details of this survey.) Zdev has no parents or mentors who have worked as computer scientists or engineers.

Zdev was generally quiet in class, interacting with one or two other students or working alone. Nevertheless, he was a prolific author, writing 50 stories over the course of the unit and developing an authoritative voice as he wrote tutorials, promoted the use of variables to track state, and addressed his readers in comments within the source code. He reported that he showed his stories to friends on the school bus, and often kept working on them at home. When asked to describe his writing process, zdev wrote, "I [write my stories] at home and learn during class."

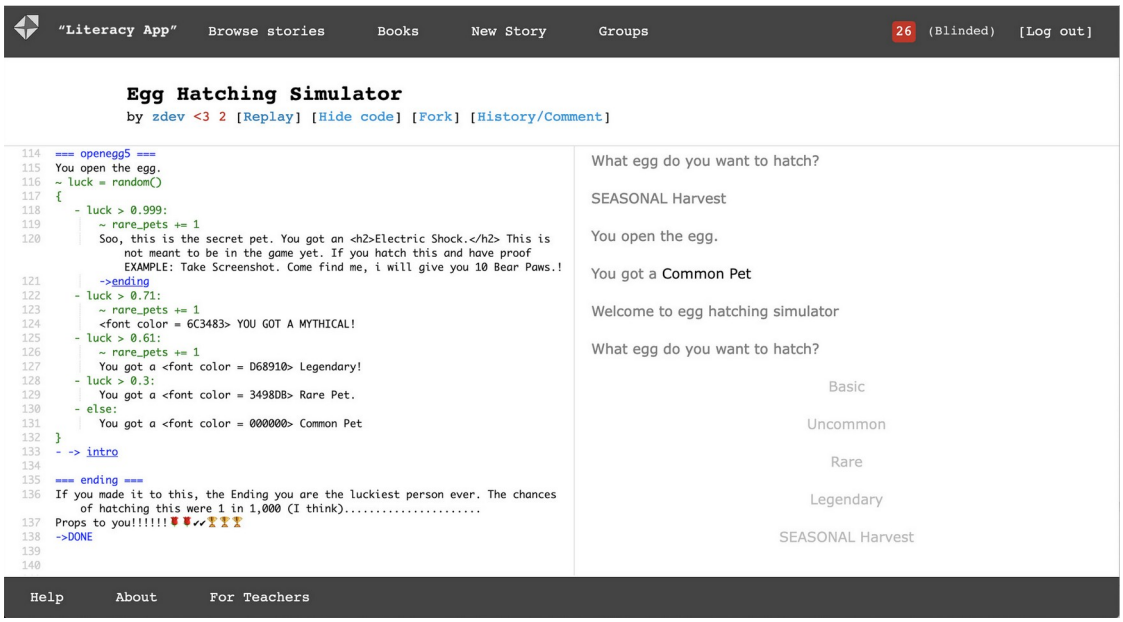

Figure 6.1: Screenshot of Unfold Studio showing zdev's "Egg Hatching Simulator."

Figure 6.1 shows the code (left) and the running story (right) of "Egg Hatching Simulator," a story by zdev. In this game the player hatches new pets from eggs, inspired by Pokémon. The code excerpt in Figure 6.1 generates a random number between 0 and 1 and then cascades through cases to determine which pet the player receives. (For an overview of Ink syntax, see Ink in Chapter 3.) If the random number is above 0.999, the player sees "Soo, this is the secret pet. You got an <h2>Electric Shock</h2> This is not meant to be in the game yet. If you hatch this and have proof EXAMPLE: Take Screenshot. Come find me, i will give you 10 Bear Paws.!" The story then redirects to the ending, which outputs, "If you made it to this, the Ending you are the luckiest person ever. The chances of hatching this were 1 in 1,000 (I think)……. Props to you!!!!!! ." This text would indeed be shown as output one time in a thousand.

The developmental trajectory of "Egg Hatching Simulator" provides a trace of zdev's process of learning to work with variables and control structures. zdev developed "Egg Hatching Simulator" over 74 edits spanning four days near the end of the unit. (He returned to the story and substantially expanded it over the summer, after the period of this study had ended.) A qualitative analysis of these edits suggests they can be clustered into five phases which are described in Table 6.1. (Details on the analysis of story edits are described in the methods section.)

Table 6.1: Five phases of zdev's development of "Egg Hatching Simulator"

Edits	Timeframe	Editing activity	Audience activity
0-12	Day 1, in class	Tinkering and adapting a template; debugging syntax	Low (4)
13-25	Day 1, After class	Building out the story; debugging flow	Medium (28)
26-41	Day 2	Extending the story	High (126)
42-49	Day 3	Polishing, adding style	Low (8)
50-73	Day 4	Probabilistic reasoning	High (108)

During the first 90-minute block period zdev began by pasting in code from a teacher-provided template which samples a random variable and then implements a probability distribution using a cascade of conditional statements, similar in form to lines 116-132 shown in Figure 6.1. He then tinkered with the original example, which simulates buying a lottery ticket, by adding a variable to track winnings and adding additional cases. During this tinkering, zdev went through numerous cycles of making syntax errors and then debugging. Later that day, zdev's attention turned to developing the story's flow, and integrating the code for a probability distribution so that the story

chooses what kind of pet will hatch from the egg. Debugging continued in this second phase, though it was more oriented to debugging control flow.

Each of the following three phases took place on a subsequent day, and were characterized by distinct activities. In the third phase, the story grew in length as zdev extended the story by copying and modifying the code he had developed to handle multiple cases (e.g. hatching a basic egg or a rare egg). In the fourth, zdev polished the user experience by adding narrative flourishes and HTML formatting, which is not officially supported by Unfold Studio, but which was explored by a small cluster of students including zdev and Eragon (introduced in Chapter 5). Finally, in the fifth phase zdev engaged in probabilistic reasoning, tweaking the parameters of the probability distribution and adding comments and assertions about probability in text the player might see as well as in comments within the source code.

This text is likely intended to be read by peers who choose to read the game's source code in addition to playing. Important computational concepts are expressed and framed in the context of speaking to an audience of gamer-programmers, as insiders in-the-know. In positioning the player as being extremely lucky ("1 in 1,000"), zdev makes a probabilistic assertion grounded in a fairly complex code structure, and does so in an interactional context which positions him as an authoritative explainer and the reader as an interested colleague.

During these phases of development, the extent to which zdev engaged with his peers' stories fluctuated substantially. The figures reported in Table 6.1 count the number of times zdev viewed, loved, or forked another user's story during each phase. (Again,

details follow in the methods section.) Even without accounting for the different time spans of each phase, it is clear that zdev's interaction with peer stories was different in the third and fifth phases. During these phases, zdev was shaping "Egg Hatching Simulator" into a recognizable genre (phase three) and developing an authorial voice which positioned both him and his audience as interested in probabilistic reasoning (phase five). Each of these practices is fundamentally dialogic: it requires careful attention to both the expectations of the intended audience and one's positioning as an author.

By the end of the unit, zdev had integrated his literacy participation with disciplinary practices, allowing him to articulate goals for his program aligned with how he had positioned the game in its genre, and then to enact them. When he released his final version, zdev advertised it to his followers with the following message: "Welcome to Egg Hatching Simulator! CURRENT FEATURES– - 4 Pets (Maybe 5?!?!) - 5 New Eggs to hatch! - *LIMITED* Summer Egg has Arrived! This will be removed on June 9! - Thanks for playing!" His playful hint toward a possible fifth pet continues zdev's earlier discourse in the source code comments about how it is possible (but extremely unlikely) to hatch the secret pet. The promotional voice with which he addresses his audience suggests identity practices grounded in social media commercialism, where everything is quantified and commodified.

"Egg Hatching Simulator" was one of a series of increasingly-ambitious projects through which zdev developed as a computer scientist over the course of the unit. By any of the summative measures I collected, zdev was quite successful. This case study is an

example of a student for whom participation as an author and as an audience member offered rich opportunities for computer science learning. Within this context, zdev grew through sustained individual practice developing and debugging a story. In the rest of this chapter, I extend these hypotheses from an individual case study to a quantitative analysis of all participants.

Research questions

In this chapter, I argue that these literacy interactions, in which students are positioned as authors and as audience, were the basis for a kind of computer science meaning-making for and with others. Furthermore, zdev's case study illustrates a phenomenon I repeatedly noticed during the unit, that literacy participation was effective when it motivated students to go back to their own stories. (In contrast, I occasionally saw students idly browsing peer stories in a manner which did not seem very productive.) To the extent that these were widespread phenomena, it would also be valuable to know how much this was simply a result of students having an opportunity to exercise existing interests, and to what extent it created the conditions for new practices. The former would be valuable in itself, but the latter would be particularly important for showing that interactive storytelling was also effective for students who did not have a prior interest in computer science, perhaps by building on their existing literacies, as analyzed in Chapter 5. These questions are formalized in the following research questions:

1. Is participation in interactive story-based literacy associated with computer science learning?
2. If so, is this association mediated by individual student practice in writing their own stories?

3. If so, do these effects remain when controlling for prior interest in computer science and literature?

Methods

This methods section builds on Chapter 3, where I report methods and context for the dissertation as a whole. Figure 6.2 presents the subset of Figure 3.5 from Chapter 3 which pertain to this research question.

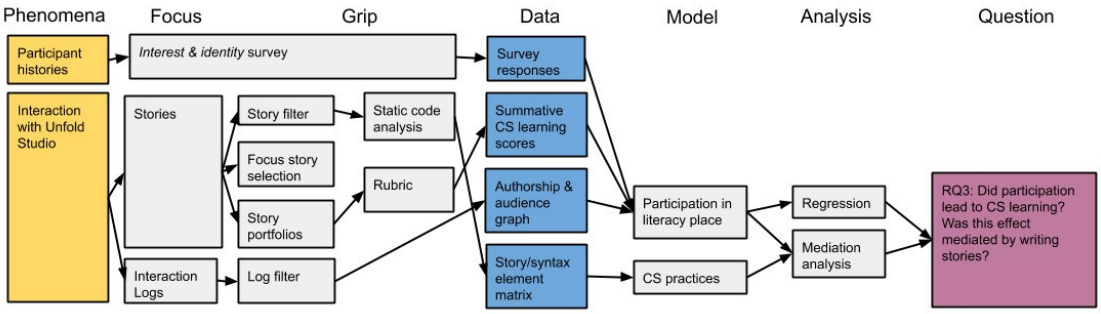

Figure 6.2: Overview of methods for RQ3

Focus

This chapter's research questions apply to all 49 students participating in the research. Students were excluded from particular models when data points were not available. For example, a number of students did not fill out the survey on prior interest and experience (or did not provide their names), so they could not be included in the third analysis (shown in Figure 6.6). The number of students included is reported with each model.

In deciding which stories to consider, I used the same filter as described in Chapter 4, removing duplicative and trivial stories. After this filter, there were a total of 578 stories.

Grip

Summative Assessment of computer science learning

At the end of the unit, each student submitted a portfolio of their two best stories: one that showed off their technical skills and one that showed off their storytelling skills. In this chapter, I consider only the technical skills submission. These stories were assessed according to a rubric (see Table 6.2). Students were familiar with the rubric from in-class activities and from feedback on drafts. The technical skills rubric emphasized two concepts: flow and state. These objectives correspond to the K-12 CS Framework's Algorithms and Programming concepts of "Control" and "Variables" ("K-12 Comptuer Science Framework," 2016). The distribution of students' scores on this assessment (flow and state combined) was roughly normal, with a mean of 4.22 and standard deviation of 2.01.

Table 6.2: Summary of the story portfolio assessment rubric

Level	Flow criteria	State criteria
Advanced (4 points)	Meets criteria for Proficient AND use of flow adds meaning to the story. Uses an advanced flow control structure.	Meets criteria for Proficient AND use of state adds meaning to the story. Uses at least one declared variable.
Proficient (3 points)	Uses diverts correctly and meaningfully to control story execution.	Uses variables (either built-in or declared) to keep track of something in the story and using it to change what happens in the future.
Basic (2 points)	The use of flow might be based closely on another story. The use of flow might "check the boxes"	The use of state might be based closely on another story. The use of state might "check the boxes" but

	but not have much effect on the story. May include minor errors in usage.	not have much effect on the story. May include minor errors in usage.
Below basic (1 point)	Does not meet criteria for Basic.	Does not meet criteria for Basic.

Literacy Events

I operationalize "literacy events" as actions taken by users in the process of reading and writing stories, as well as browsing, searching, following other users, and commenting on stories. In this study, I consider only those literacy events in which one user views, loves, or forks (makes a copy of) another user's story. These interactions feature two important, reciprocally-connected roles, those of author and audience. As described in the background, I view these as important learning opportunities within a literacy place grounded in, but extending beyond, the classroom. Each literacy event can be considered as a link in a bipartite network of authors and stories. We define a user's author score as the number of literacy events in which another user interacted with one of the user's stories. Similarly, a user's audience score is the number of literacy events in which that user interacted with a story written by another user. Figure 6.3 shows a histogram of participants' author and audience scores.

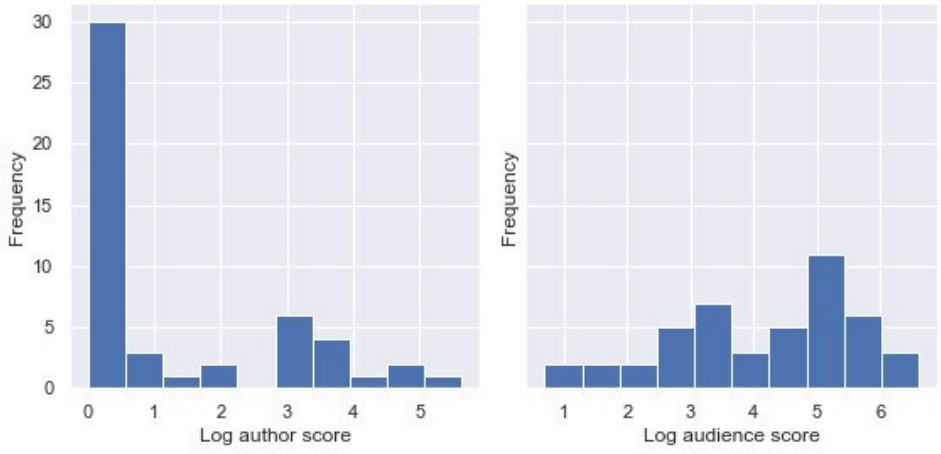

Figure 6.3: Histograms of author score and audience scores

Thirty of the fifty study participants have author scores of zero because they chose not to make any of their stories publicly visible to their peers. (While this group wrote fewer stories on average than authors with positive author scores, they still wrote an average of 8 stories.) Note that the sum of all participants' author scores does not equal the sum of all participants' audience scores because these scores consider interactions with all Unfold Studio users. Some participants wrote stories which became popular on the site beyond the classes involved in this study, and they were occasionally inspired by stories written by external authors. For example, a student at another school wrote a story in which the player walks through an imagined monument to LGBTQ heroes from history. Several students referred to this story as influencing their own planning and writing.

Practice with computational concepts

The second research question considers whether the hypothesized association between literacy participation and computer science learning is mediated by individual student

practice with computational concepts within their own stories. The best view of student practice would come from a qualitative analysis of the developmental trajectory of stories, as presented in zdev's case study. However, this is not feasible for all 578 stories in the corpus.

I therefore consider a simpler measure of story content. I conduct static program analysis of the code from the final state of each story. (The left pane in Figure 6.1 shows an excerpt of a story's code.) Following a common strategy of counting syntactic elements which map to concepts (e.g. Brennan & Resnick (2012); Fields, Quirke, Amely, & Maughan (2016)), I count the use of syntactic elements which correspond to flow and state, the two primary computer science learning goals of the unit.

I chose to count the number of diverts in each story as a measure of practicing flow. An interactive story can be visualized as a directed graph, where each knot, or chunk of textual content, is connected to other knots by edges. Each divert (->) implements an edge, so the number of diverts in a story corresponds to the number of edges in its story graph. We defined a students' flow practice score as the logarithm of the maximum number of diverts in any of an author's stories. (Using the sum across an author's stories would be artificially inflated when authors repeatedly forked their own stories, and using an average would be artificially deflated for authors who made numerous throwaway stories for notes or to test out constructs.). I conducted a similar analysis for stories' use of state, but do not report that here.

Prior interest and experience with computing and textual literacy

Additionally, some data about participant histories was captured through an initial survey asking students demographic information such as race, gender, and prior experience with and interest in computing (Friend, 2016). I extended this survey with comparable questions about textual literacy practices. For this study, I focused on prior interest in computer science and in textual literacy.

Data

To summarize the processes described above, the data considered in this chapter can be represented in a single table with one row for each student, containing the following columns:

- Technical score (Summative computer science learning)
- Author participation score
- Audience participation score
- Flow practice score
- Prior computer science interest score
- Prior textual literacy interest score

Model & Analysis

The first research question asks whether there is an association between literacy participation, either as author or as audience, and computer science learning as framed above. This question has two cases, each of which can be modeled by OLS regression models as shown in the path model in 6.4.

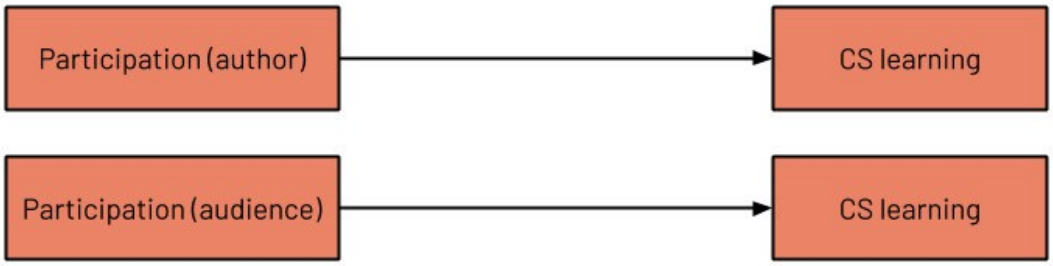

Figure 6.4: RQ1 hypothesizes an association between literacy participation and computer science learning

If there is indeed a significant association between literacy participation and computer science learning, the second research question asks whether that association is mediated by computational practice. For zdev, there was clearly an interplay between his literacy participation and his practice with computational content in his stories which, the case study above argues, supported his computer science learning. Several other authors published stories which served as tutorials, for example explaining to their peers how and why they should use variables in their stories. Like zdev, their engagement with the computational concepts and their literacy participation were fundamentally intertwined. The proposed mediation (to be analyzed separately for audience participation and authorship participation) is shown in Figure 6.5.

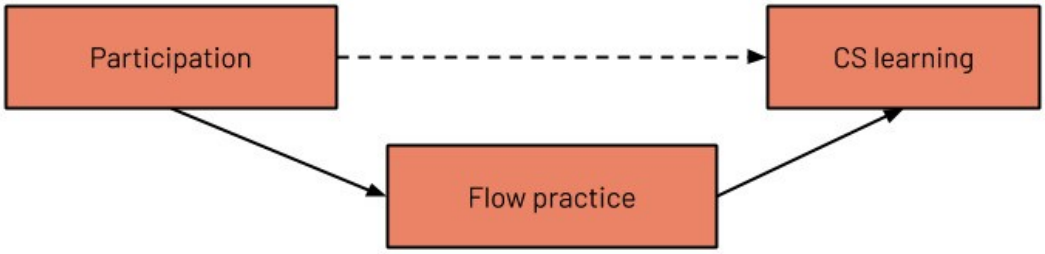

Figure 6.5: RQ2 hypothesizes that the association in RQ1 is mediated by computational practice

I tested this hypothesis using Baron & Kenny's (1986) method for mediation analysis. Research question 1 will (hopefully) show a significant association between author/audience score and summative technical score. Then it is necessary to show that the association between author/audience score and flow practice, as well as the association between flow practice and summative technical score, is significant. Finally, it is necessary to show that the effect size for author/audience score is reduced when flow practice is added to the model. I used structural equation modeling as implemented in the R lavaan package (Rosseel, 2012) to estimate effect sizes and significance of the latter associations. Additionally, I tested this hypothesis using bootstrap significance testing as implemented in the R mediation package (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014) and found comparable results.

One issue that needs to be addressed is that mediation analysis assumes causality: if X does not have a direct causal effect on Y, then there is no sense in which that effect can be mediated by factor M. Since this study is nonexperimental, causality cannot be assumed from the study design. Nevertheless, mediation is used in nonexperimental contexts (Shrout & Bolger, 2002). The approach I take in this dissertation is to rely on

qualitative analysis such as case studies and literary analysis to show that phenomena exist and how they worked for some individuals. Even when this approach is persuasive, it leaves the possibility that the subject of the case study was an outlier, that even though a phenomenon was important for her learning, it was not generally important. I rely on statistical claims to provide evidence that phenomena exist broadly among the cohort of participants.

This approach is not completely satisfying. Even if the reader is persuaded of a causal relationship in a case study, on what basis should the causal assumption be extended to the other participants' experience? However, I believe it is the best available approach. The experimental alternative would present serious issues of external validity, as the conditions and assumptions required for an experimental approach would have been a poor fit for the complex and emergent nature of a literacy space framed as a figured world.

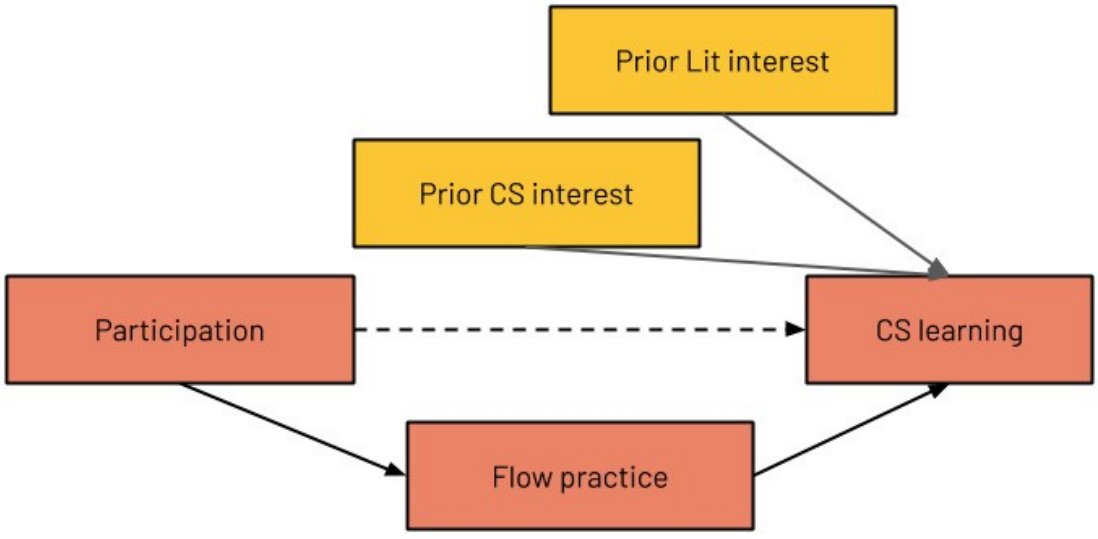

Figure 6.6: RQ3 asks whether the association in RQ1 is moderated by prior interest

Finally, the third research question asks about interactions with prior interest in computing and literature. These interactions could help interpret the relationship between the literacy place supported by Unfold Studio and the background learning ecology that existed for participants. If Unfold Studio was generally effective in supporting computer science learning, for whom was it more so and for whom was it less so? This analysis could also help to make the results from the second research question more persuasive by eliminating potential alternative explanations for the association between literacy participation and the summative assessment.

Results

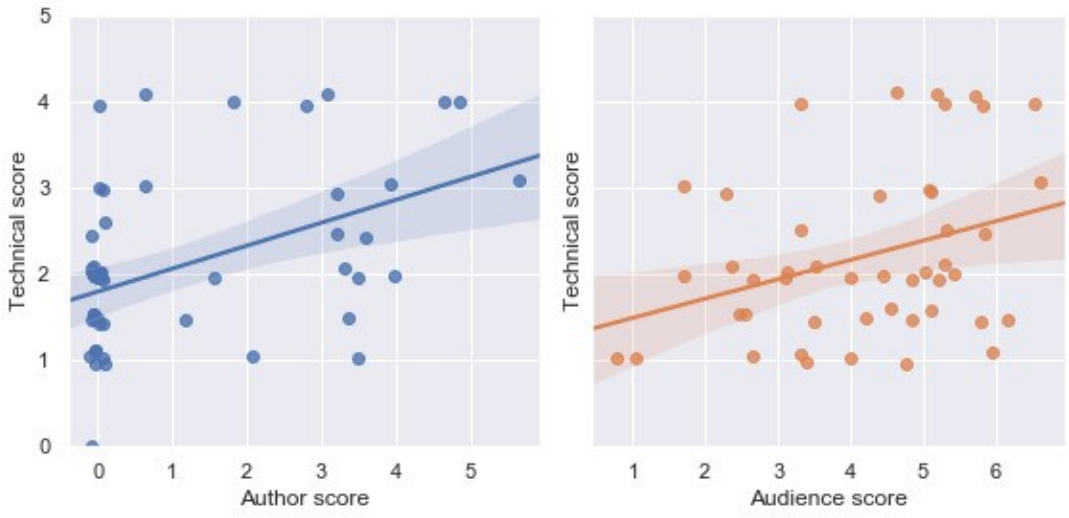

Figure 6.7: Regression plots showing association between summative technical score and (a) author score and (b) audience score. Shaded bands indicate standard error of the model's intercept and coefficient.

There was a statistically-significant association between both author and audience scores and summative performance. Plots of these associations are shown in Figure 6.7 and regression tables are shown in Table 6.3. There was a significant positive association

between technical score and both author score and audience score. Students who participated more in the literacy place, as authors and as audience, tended to have higher scores on the summative assessment of Computer Science content. This suggests that writing for an audience, as well as participating as an audience of others' work, was associated with better performance on the technical summative assessment. There was a substantial correlation between author score and audience score ($r^2 = 0.36$), which explains the collapse of model 3 in Table 6.3 due to collinearity. In other words, students with high author scores were reasonably likely to also have high audience scores. Intuitively, this is not surprising, as I hypothesize that these are reciprocal, dialogic relationships.

Table 6.3: Regression table for summative technical score (: p<0.1; **: p<0.05; ***: p<0.01)*

	Model 1	Model 2	Model 3
Author score	0.241*** (0.081)		0.170* (0.101)
Audience score		0.202** (0.092)	0.083 (0.115)
Constant	1.797*** (0.163)	1.317*** (0.407)	1.601*** (0.432)
Observations	49	45	45
adjusted r^2	0.139	0.079	0.117
Residual Std. Err.	0.937 (df = 47)	0.914 (df = 43)	0.895 (df = 42)
F Statistic	8.773*** (df = 1; 47)	4.780** (df = 1; 43)	3.918** (df = 2; 42)

Mediation by story content

Having found an association between literacy participation and summative score, I further hypothesized that this association was mediated by practice with computational

concepts, as measured by the content of authors' stories. The results, shown in Figure 6.8, indicate that flow practice significantly mediates both relationships. Following Baron & Kenny's (1986) approach to mediation, Figure rq2_results shows that for both author score and audience score, when flow practice is introduced as a mediator, the direct effect is lessened while both associations in the part of mediation have large, statistically significant effects. Bootstrap mediation analysis gave similar results, finding that almost half (0.464) of the association between author score and summative technical score was mediated by flow practice, as was almost three quarters (0.721) of the association between audience score and summative technical score.

In other words, if we accept that there is a causal relationship between participation as author and as audience, these results show that the mechanism is that participation leads to more computational content in stories, which leads to more computer science learning. This corresponds with the Vygotskian intuition that social practices are internalized into cognitive structures through performance.

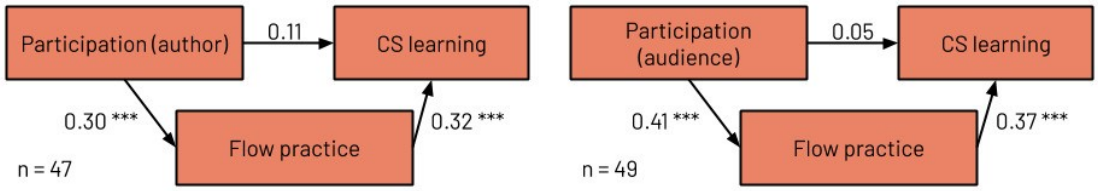

Figure 6.8: Path model showing the results of RQ2.

Finally, the third research question introduces prior interest in computer science and in literature. Figure 6.9 shows that the mediated effect of participation (both authorship and audience) on computer science learning remains substantial and

statistically significant. If we sustain the assumptions made in the prior results, this third set of results provides evidence that the effect represents more than an opportunity to participate for youth who were already prepared to do so.

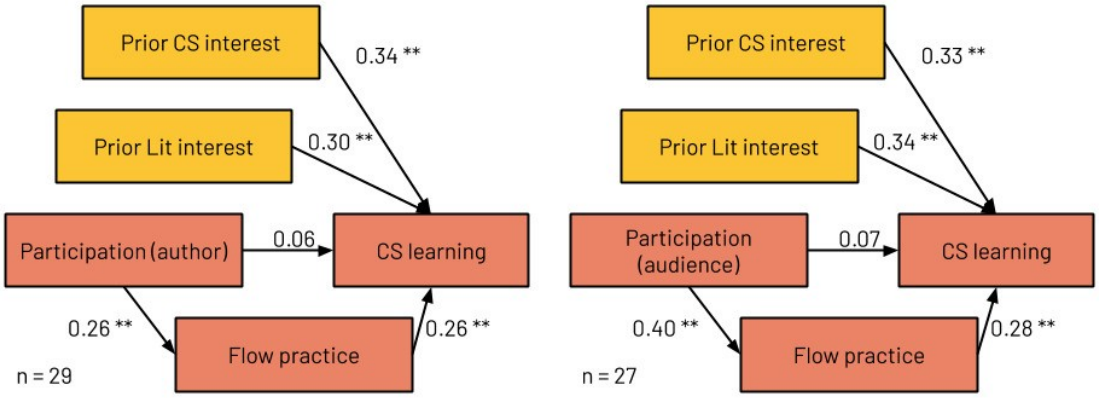

Figure 6.9: Path model showing the results of RQ3.

It is no surprise that prior interest in computer science was associated with more computer science learning. The association between prior interest in literature and computer science learning suggest that connections across literacies, such as those explored in Chapter 5 may have been important. However, the fact that the effect remains after controlling for these covariates also suggests that Unfold Studio was also effective for students with no prior interest in the practices it supported.

Discussion

In this chapter, I have shown that literacy participation, as an author and as audience, was associated with computer science learning as assessed by a summative assessment. This will be entirely unsurprising to educators and researchers with a sociocultural orientation. However, there is very little quantitative work in K-12 computer science education

showing the summative effects of participation. Beyond justifying further research with Unfold Studio, these results will be important in making the case for sociocultural pedagogies in K12 computer science.

Furthermore, I showed that both associations were mediated by flow practice, a measure of students individually engaging with computer science concepts in their own stories. These results support my broad hypothesis that a literacy-based approach to introductory Computer Science can provide an effective learning environment. The fact that these results were not substantially affected by the inclusion of covariates measuring students' prior interest in Computer Science and writing suggests that this approach could be particularly effective for broadening participation in computing practice. Indeed, on the exit survey numerous students wrote that writing interactive stories was different from what they expected programming to be, and that they enjoyed computer science much more than they thought they would.

Even though these associations remain when controlling for prior interest in Computer Science and English/Language Arts, it is possible that I have missed hidden variables accounting for both students' participation and their scores on the summative assessment. Moreover, as noted above, these results depend on the assumption of causality. My arguement that qualitative evidence provided here and in other chapters provides evidence for a causal interpretation of the associations found here is more in line with Pearl's (2009) argument for a commonsense understanding of causality rather than Hume's (2018) fundamental skepticism about ever showing causality.

In the course of this analysis, I developed author score and audience score as measures of participation in the classroom literacy place. The results show alignment between a traditional cognitive (or competency-based) measure of learning, and two measures based on students' participation in a community of computational practice. In future research, I intend to center participation in a community of practice as a primary form of learning, producing quantitative measures which can be held up against cognitive assessments. The challenge then will be to justify that the participation, the community of practice, and participants' enacted identities are legitimate forms of Computer Science. I do not envision a reconciliation or unification of cognitive and sociocultural approaches (e.g. Billett (1996)); rather my goal is to highlight the tradeoffs of each approach and possibly displace cognitivism as the default presumed to be most legitimate. Social learning analytics combined with qualitative analysis will be invaluable tools in this task, as they will provide a high-granularity view of the nature of students' practice. It seems likely that author and audience scores are a coarse view on emergent dynamics in students' trajectories of participation; future research will further explore these dynamics.

Conclusion

Summary

The last three chapters addressed three research questions. As shown in Figure 7.1, two were questions about design and two were questions about theory. In the realm of design, I asked how participants used Unfold Studio's textual and computational affordances to create meaning and critical possibilities (RQ1). The theoretical questions asked how students connected their broader literacies to classroom practice (RQ2) and how classroom practice contributed to computer science learning (RQ3). This conclusion summarizes the findings of the design conjectures and theoretical conjectures explored over the previous three chapters and suggest the ways they help advance several academic fields. I close by proposing a future research agenda.

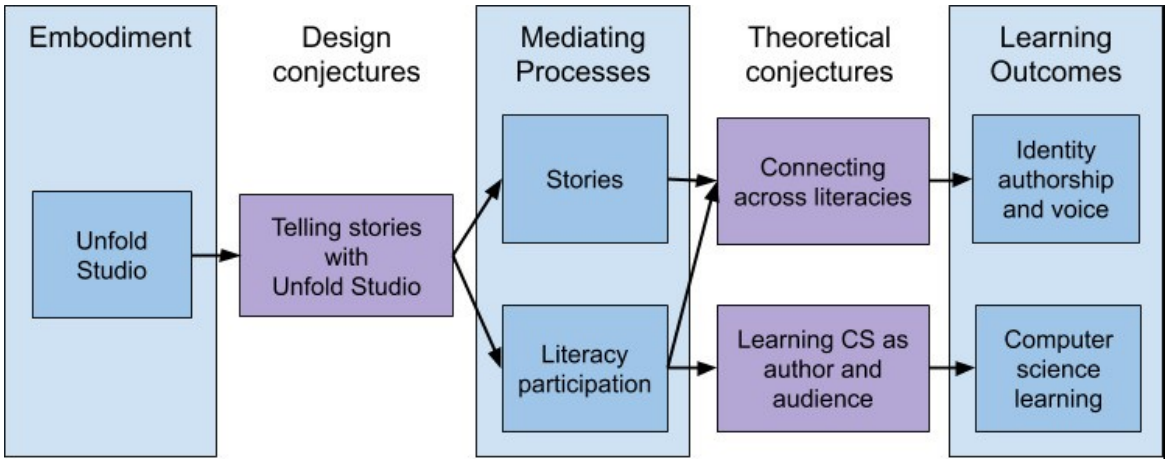

Figure 7.1: Conjecture mapping showing the three primary research questions

Chapter 4 analyzed how authors used the literary and computational affordances of Ink and Unfold Studio toward rhetorical and critical ends. This analysis clarified the

mechanics of how participation in interactive storytelling can lead to critical change in the subject positions and genres which mediate and frame participation. Finding new ways to use a medium means transforming the medium, along with the genres it encodes. Treating infrastructural media as malleable rather than fixed is a step toward a re-visioning of K12 computer science aimed at transformative possibilities rather than predetermined outcomes. The chapter closes with a call for centering critical computational literacies as a goal for K12 computer science.

Chapter 5 zoomed in on several case studies to analyze how participants connected their existing literacies to the classroom literacy place. Through identity authorship and channeling voices, they wrote interactive stories which critically reconfigured the subject positions and genres of the classroom literacy place to make room for their desired identities and voices. This chapter paid particular attention to the role of media infrastructure (in this case, Unfold Studio and the Ink language) in connecting literacies to one another and in encoding the literacy place's subject positions and genres. Eragon's "fictional engineering" was at once working with computational ideas and critically imagining alternative social orders.

Contributions

This dissertation makes several contributions to the fields of learning sciences, literacies, and computer science education. First, the concept of critical computational literacy is theorized more specifically than it had been before, and it is grounded in constructs and methods which are important to both the learning sciences and to literacy studies. By conceptualizing literacy as a particular kind of figured world in which interaction with

texts has particular importance, I identified two axes of literacy: one radial, traversing scopes of practice from cognitive to situated to critical; and one connecting practice to infrastructural media. This framing extends diSessa's (diSessa, 2001) analysis of cognitive and social material intelligence to a critical scale, positioning communities of practice as places within larger spaces organized by power relations.

Identity authorship and channeling voice are identified as dialogic forms of critical action, allowing participants to transform the subject positions and genres which mediate and partially-define who they can be and how they can participate. Subject positions and genre are encoded in the infrastructural media supporting a literacy place, so critical action operates on both dimensions of literacy at once: changing the conditions of situated participation also involves learning how to skillfully use the medium. This is a particularly appealing construct for computer science education, which has sometimes defined its core content as abstract and detached from real-world concerns, limiting its appeal to marginalized youth, limiting its ability to critically analyze its own role in producing marginalization, and leading to awkward forms of interdisciplinarity where justice-oriented applications of computer science are not framed as computer science itself.

Through several publications I have been developing an argument for understanding computational thinking in cognitive, situated, and critical terms, and ultimately for reframing computational thinking as computational literacy. This framing helps distinguish the goals of various computational thinking initiatives and puts them in dialogue with one another (Kafai et al., 2019). Reframing computational thinking as

computational literacy also surfaces forms of critical action such as identity authorship and channeling voices, and makes available decades of scholarship from literacy studies on issues such as how and whether to teach the culture of power (Delpit, 1988). Interfaces (both identity-as-interface and computational interfaces) are centered as important sites for analysis of how the arrangement of subject positions and genres is a form of power.

This dissertation also offers progress on practical, methodological, and design issues in computer science education. The analysis of how participants used interactive storytelling (via Ink and Unfold Studio) to connect literacies supports further development of Unfold Studio and more generally how infrastructural media can support the emergence of different kinds of critical literacy places. I proposed an extension of reader-response literary analysis as a form of assessment in literacy-based computer science and developed quantitative measures of participation via authorship and audience which can support future research on participation in computational literacy. The development and analysis of transliteracy pedagogies engaging participants' geographic and computational literacies opens possibilities for future design of connected learning environments. The dissertation's illustration of these tools and practices is important, as my call for literacy-based computer science challenges several decades of advocacy aimed at articulating a single operational definition of computer science (Barr & Stephenson, 2011).

Next steps

This dissertation frames my future research agenda. First, I would like to strengthen and extend some of the research presented here. I intend to continue developing Unfold Studio's interface and to research how different literacy places in different communities where it is used. Due to resource limitations, the I was the only coder for the rhetorical and reader-response analysis of student-authored stories addressed in the first two research questions. I plan to systematize this coding so that inter-rater reliability can be established, and to systematically include research participants in analyzing the significance of their stories through coding. Similarly, I plan to conduct a more methodical validation of the measures of authorship and audience participation used in the third research question.

As I prepare to make a deeper commitment to a university, to a city, and to its school communities, I also hope to develop methods which are more inclusive of research participants and which serve them in concrete ways. While in retrospect I should not have been surprised, I was troubled by the reluctance of many students to participate in the research, and by the distrust with which some viewed me, my cameras, and the field of computer science. I honor and respect these feelings, and am proud of the ethical conduct of this research. Still, what else could have been possible? I am inspired by methodologies in which participants participate in the entire research process, from grantwriting to coming to own the research outcomes through their own practice.

In addition to deepening and extending the present analysis, this research has made me curious about several new directions. First, I am interested in identity and embodiment. Throughout this research, identity, framed as an interface "between intimate

discourses, inner speaking, and bodily practices formed in the past and the discourses and practices to which people are exposed, willingly or not, in the present" (Holland et al., 1998, p. 32). The outer surface of identity was discussed extensively here, especially the relationship between identity and subject positions. I often describe the goal of critical action as creating room in the literacy place for who you want to be and how you want to speak. But how do we come to desire certain identities or to feel that certain voices are a good fit? Does literacy place a role in producing these self-understandings? Starting with Butler's (1997) analysis of desire and embodiment, I want to explore how embodiment relates to identity.

I am also interested in *mind*, another construct that is understood to be "inside" of identity but implicated in social practice, particularly in the manipulation of symbolic systems. As with embodiment, I am interested in the relationship between mind and literacy. Olson's (2016) *Mind on Paper* proposes that "reading and writing provide both the structure and occasion for talking about language, that talking about language requires a meta-language and that a meta language is the key to the development of a particular form of rationality." (p. 15). What I find particularly intriguing is that Olson locates mind not somewhere inside, but in the representation, at the interface. My insistence throughout this dissertation on dialogic understandings of identity and voice is rooted in my skepticism of looking inside for the true, authentic self. Exploration of the idea of mind-as-self-referential-interface feels particularly promising as we transition from paper to computation. The essence of symbolic programming is its ability to treat instructions as data, including the ability for a program to operate on itself (Graham,

2002; MacCarthy, 1960). I view my research with Unfold Studio as working toward media that could do for computational mind what literature has done for the mind on paper.

Third, I am interested in researching computational literacies in learning ecologies beyond the classroom (Gutiérrez, Bien, Selland, & Pierce, 2011; Hecht & Crowley, 2019). I would like to extend my work analyzing and designing for critical possibilities into the multiplicity of literacies which mediate our interactions, opportunities, and sense of place in everyday life. Digital and geographic space are increasingly enmeshed (Zuboff, 2019), and literacy could be an important construct for studying opportunities to participate in the power which orders technosocial situations. For example, Google's Sidewalk Labs proposed to develop a neighborhood in Toronto as both a physical entity and as software. The full extent of Google's proposal, which was not initially made public, would have given the corporation control over the district's tax and financing authorities, public services, schools, transit systems, policing powers, and criminal justice system (Cardoso & O'Kane, n.d.). However benevolent the proposed administration, this is a totalitarian vision. As I prepare to take up my research work in Buffalo, I find myself wondering what a more just and participatory computer city might look like.

Computers and computer science have remade our worlds. The potential of education to produce computer culture (or at least to shape computer culture) through which we might learn how to live well in these new worlds remains unrealized. My goal in researching critical computational literacies is to help create the conditions by which everyone can participate in these cultures and help decide what they should be. At a

recent online conference on speculative education, K. Wayne Yang articulated this by quoting Audrey Lorde's "A Litany for Survival." "I'm interested in the now," he said. "The now that breeds futures…"

looking inward and outward
at once before and after
seeking a now that can breed
futures
like bread in our children's mouths
so their dreams will not reflect
the death of ours;

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