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Fabricating response: Preservice elementary teachers remediating response to *The Circuit* through 3D printing and design

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ABSTRACT

Building on sociocultural theories of literacy learning, in this article, we think at the intersection of reader response theory and multimodal literacies to examine how 13 preservice teachers in the course Teaching Social Sciences Through the Arts remediated responses to Francisco Jiménez's *The Circuit: Stories From the Life of a Migrant Child* through additive manufacturing (i.e. 3D printing) and arts-integrated making. Through qualitative analyses of participants' in situ processes and product(s), we identified a range of ideological and material supports and constraints during the digital fabrication process. Reading and responding to text—as mediated actions and events—became iterative spaces wherein individual understandings of text transformed into encounters of difference. Suggesting that participants' artifactual responses at times operated as critical literacy texts, our analyses of 3D fabrication and remediated responses led us to consider how modalities of composition yielded unique affordances and constraints to the ways readers encountered texts and expressed and responded to controversial social issues.

When the 45th president of the United States took office in 2017, anti-immigrant rhetoric and action swelled. From his campaign promise to build a wall along the southern US border to @POTUS tweets suggesting that the country was undergoing an immigrant invasion, his actions resulted in a rise of xenophobia that contributed to increased fear and anxiety in youth of Color—what some call the Trump effect (Costello, 2016). Moreover, acts of dehumanization occurring under Trump's administration were at times quite visual. Images of children in detention cages wrapped in foil, for example, rightfully haunted the national consciousness during this time. In response, activist artists, designers, and architects used the arts to provoke compelling counterstories of migration. Whether it was JR's (2017) *Giant Picnic* (a photograph of a Dreamer's eyes that served as a physical table spanning both sides of the border) or Ronald Rael and Virginia San Fratello's (2019) *Teeter-Totter Wall*, art revised how borders—as concepts and as physical environs—operated. In other words, art worked as a technology to reveal alternative social and political possibilities.

In education, the arts, or arts-integrative practice, is often used to forward creative thinking and engage students in cross-disciplinary learning.[1] What constitutes the arts has received thoughtful, critical attention grounded in tenets of critical race theory in the last decade, specifically regarding how the arts are linked to Eurocentric ideas that center White values and practices.[2] In this article, we center one activity in the course Teaching Social Sciences Through the Arts designed by Jon and Melita. This course worked with and against institutionally constructed definitions of the arts to prepare students for building curriculum based on the national and state arts standards. Beyond learning about institutionally sanctioned artists' work and community-based work on the periphery of institutions, we also invited students to respond to open-ended prompts through materials, including song and body movement. In doing so, we hoped preservice teachers (PTs) would come to interact with the arts as a process of meaning making, similar to the ways *making* has been taken up in recent literature from informal learning environments (see, e.g. Vossoughi et al., 2016). Throughout this article, we use the terms *arts-based responses*, *the arts*, *arts integration*, and *making* to describe how PTs worked with materials to make their learning and thinking visible to one another. Given that most schooling spaces rely primarily on verbal or written communication—a legacy of an Enlightenment-era prioritization of a thinking mind over a thinking body—we intended the activities we designed to create experiences with material resources PTs might encounter in their classrooms. As such, we hoped the PTs might become comfortable opening up disciplinary possibilities for meaning making in their future curricular design.

Much of the scholarship on arts integration in literacy classrooms has taken on a definition of the arts aligned with institutional understandings. Dobrick and Fattal (2018) argued that viewing and interacting with works of art can also advance interpersonal awareness and issues of equity, as well as help people navigate themes of social justice. Similarly, Garrett and Kerr (2016) offered a framework for considering the multidimensionality of aesthetic texts as tools for moving past historical facts towards meaning and social significance, engaging learners to respond to the ambiguity of historical events and contexts. This framework aligns with Chang et al.'s (2012) approach to art education that foregrounds a critical exploration of visual culture, which takes up the critique of cultural production to reveal how "visual experience and the visualized subject are constructed within social systems, practices, and structures" (Tavin, 2003, p. 209). In teacher education methods courses, engaging the visual to further non-arts curriculum development has primarily been taken up in two ways: the observation of and exposure to visual resources and the production and creation of physical artefacts (Oreck, 2004). In most cases of arts integration, however, PTs are not required to produce their own artwork but rather encounter and respond to the work of others.

Alternatively, incorporating making as an integral form of instructional design involves going beyond the viewing of works of art to the creation of expressive artefacts—an approach that reflects "practical, physical, and playful modes of inquiry" (Vossoughi & Bevan, 2014, p. 4) and constructivist theories of learning. This approach is well suited to mediate responses to and discussion of contemporary issues often considered too controversial for elementary education (Chang et al., 2012). Link (2021), for example, pointed to the importance of PTs creating their own works as a way to

critique symbols and stereotypes that can counter master narratives and demonstrate contradictions with lived experiences. Artist Yong Soon Min (1996) captured this relation well when she recounted the following about her artistic process:

> Art making for me is a process of discovery and learning about myself and my relationship to the world. This art-making process also involves my desire to communicate and to share this exploration and understanding with others and thereby complete the dynamic. (p. 141)

Thus, art, particularly the process of making art, creates opportunities for dialogic encounters with oneself, others, and the world. As a practice, it simultaneously recognizes and refuses singular or dominant stories.

In this project, we focussed on the collaborative act of making in the teacher education classroom to examine how PTs in the course Teaching Social Sciences Through the Arts used elements of additive manufacturing (e.g. 3D printing) to fabricate responses to Francisco Jiménez's (1997) autobiography, *The Circuit: Stories From the Life of a Migrant Child*. By taking up a medium (3D printing) in non-traditional ways—as an affectively charged material for expression versus designing a consumable or entrepreneurial product—we worked to challenge the ways such materials have been taken up in dominant making practices. More specifically, we asked two research questions:

1. How do 13 PTs in the course Teaching Social Sciences Through the Arts leverage 3D printing and design to respond to Jiménez's (1997) *The Circuit*?
2. What are the mediational affordances and constraints in PTs' fabricating responses?

Suggesting that artifactual responses at times operated as critical literacy texts, our analyses of 3D fabrication and remediated responses led us to consider how modalities of composition yielded unique affordances and constraints to the ways readers encounter texts and express and respond to controversial social issues.

Theoretical Framework

Building on sociocultural theories of literacy learning, in this article, we think at the intersection of reader response theory (Rosenblatt, 1978; Schoonover, 2020) and multimodal literacies (New London Group, 1996). In thinking at this intersection, our goal is not just to examine how PTs leveraged the affordances of 3D printing and design as a summative artefact made for a class. Rather, we are interested in how collaborative interaction (with colleagues, tools, and technologies) and the intercontext of the teacher education classroom served as mediational means for advancing communicative expression. Thus, this remediated expression, what we refer to here as the fabricated composition, not only served as a form of literary response to *The Circuit* but also provided insight into students' understandings of a larger social issue (i.e. immigration) as it was presented in a children's text. In this section, we discuss these two areas individually and then highlight what this syncretic perspective offered our analyses and project.

Reader Response Theory

Critical to our study is the notion that literary texts "expand beyond the borders and boundaries of the printed book" (Serafini, 2012, p. 151) and require broad under- standings of what it means to be a reader. To this end, we turn to reader response theory to understand the complex ways people encounter and make meaning with texts. Reader response theorists, put simply, view reading as a transactional activity in which meaning is negotiated among readers, authors, texts, and contexts (Sipe, 1999). Rosenblatt (1978) explained how readers' experiences, emotions, and attitudes fuse with texts during the intersubjective process of reading. From her transactional perspective, response is "an ongoing process in which the elements or factors are … aspects of a total situation, each conditioned by and conditioning the other" (p. 17). Imbued with semiotic potential, readers take up texts through personalized processes of navigation, interpretation, and co-creation (Rosenblatt, 1995). In this intersubjective process, the experiences, emotions, and attitudes of individual readers fuse with a text to evoke a "poem," or what Rosenblatt (1978) defined as "an event in time … not an object or ideal entity [but] a coming-together, a compenetration, of a reader and a text" (p. 12). Response, therefore, becomes "the lived-through process of building up the work under the guidance of the text" (p. 69). It is a process of becoming.

Readers, however, do not merely consume texts. Instead, readers engage with texts in specific ways and moments that inform their meaning. For Rosenblatt (1995), texts are first "aesthetically evoked" before becoming "the object of reflection and analysis" (p. 295). Imbued with semiotic potential, readers take up texts through personalized processes of navigation, interpretation, and co-creation. Each reading, as a result, becomes "situated in dialogue with and in extension of other readings" (Smagorinsky, 2001, p. 141) and is moulded by the reader's meaning-making processes and ways of "fill[ing] in the gaps" (Youngs & Kyser, 2021, p. 267). Reading, thus, is a deeply personal act and practice that is unique to each individual.

Multimodality and Social Semiotics

In this project, we took a social semiotics perspective (Kress, 2010) to examine the affordances and constraints of 3D printing as a mode of collaborative response. A social semiotics approach involves considering how diverse modes—sounds, texts, and visuals—inform communicative meaning making. Hodge and Kress (1988) empha- sized that multimodal communication constitutes an ensemble of modes and socio- cultural practices. Hence, the process of multimodal response encompasses how "people *become* who they are and where sociocultural formations (church, state, profession, class, social group) are constantly being made and remade" (Prior & Hengst, 2010, p. 3). Sociocultural factors (e.g. histories of participation) influence how people leverage different communicative modes towards personally meaningful production.

Reading 3D Design and Printing as Multimodal Composition

Previous literacy researchers have studied how readers leverage video games (Marlatt, 2018), hypertext (Smith, 2018), collage (Lewkowich, 2019), annotated video (Corbitt

et al., 2022), digital art galleries (Jocius, 2013), websites (Doering et al., 2007), and comics (Price-Dennis et al., 2015) to make meaning of texts in personalized ways. Building on this scholarship, we considered how PTs remediated literary responses using 3D design.[3] Remediation, as Prior (2015) noted, "points to ways that all activity is (re)mediated—not mediated anew in each act—taking up the materials at hand (materials with a history), putting them to present use, and thereby producing altered conditions for future action" (p. 192). Moving away from understanding 3D printing solely as an artifactual demonstration of content, we focussed on how participants brought form and content together in ways that "explicate the relationships between human action, on the one hand, and the cultural, institutional, and historical contexts in which this action occurs" (Wertsch, 1998, p. 24).[4] More than just proxies for alpha-numeric text, material fabrication, as our findings illustrate, helped "learners engage in different processes when engaged in interpreting literature … due to the different types of representation available through each" (Smagorinsky & O'Donnell-Allen, 1998, p. 203).

Method

In this project, we drew on data from a larger exploratory case study (Stake, 1995) examining the affordances and constraints of employing makerspace technologies in a university-based elementary teacher education course. In this section, we provide an overview of the analysed focal assignment guiding this inquiry, discuss the participants and course context, and talk across methods for data generation and analysis.

Course Context

The context of the study, the course Teaching Social Sciences Through the Arts, was a semester-long class that met once a week for three hours. The course provides an overview of the content required for the Massachusetts social studies certification exam, as well as theory and pedagogies for teaching design and studio-based inquiry. In the readings and classwork, the arts played a critical role in facilitating students' encounters with primary source material, promoting civic action, and engaging students in creative processes of research and response. As instructors, Jon and Melita worked under two presuppositions: All people have the capacity to connect with making practices, and PTs are more inclined to take up unfamiliar pedagogical innovations in their future classroom contexts when they have opportunities to experiment on their own first.

Shared Text: The Circuit
Spanning two weeks, students engaged with a series of children's books and a youth text covering topics related to immigration (e.g. the migrant's journey). Together, we analysed children's books that encompass narratives, such as the journey of a Syrian refugee family during a civil war (*Stepping Stones: A Refugee Family's Journey* by Margriet Ruurs, 2016) and a family dealing with detention and separation after immigrating to the United States (*Mama's Nightingale: A Story of Immigration and Separation* by

Edwidge Danticat, 2015). During these weeks, we also assigned students to read *The Circuit*, a middle-grade autobiography by Francisco Jiménez (1997). Through the eyes of young Francisco, *The Circuit* traces his migrant family's movement from a rural farming area north of Guadalajara across the US–Mexico border and his sibling's experiences growing up amid the social and political worlds of migrant labour in the US economy. Through vignettes about his family's search for economic opportunity and stability, Jiménez details the precarity faced by migrant families as they navigate institutional systems (e.g. US Immigration and Customs Enforcement [ICE]) and the love, care, and support built from and within surrounding communities. We chose this text not only because of its focus on immigration but also because it is regularly featured in the curricular scope and sequence of the neighbouring school district.

Overview of Focal Assignment

We designed the Fabricating Response assignment to demonstrate the connections among technology, children's literature, making, and social studies. Unlike other making events in the course, this assignment mapped a very specific process for response. The 3D-printing project engaged PTs in a collaborative, semi-guided design of an artefact signalling their transactional response to one of the assigned children's books. Centering our literary inquiry on the topic of immigration, PTs responded to *The Circuit*. Using 3D modelling and printing technology, PTs discussed how their designs could enhance, affect, and/or reject their collaborative responses—and, in turn, commentaries—to the text and broader social issues.

Spanning a series of three class sessions, the project followed a three-phase model: explore, engage, and evaluate. During the explore phase, we introduced PTs to 3D-printing technologies and software, such as Tinkercad and Thingiverse. We also spent time looking at various artists' works that demonstrate experiences and themes highlighted in *The Circuit*. During the engage phase, PTs worked in grade-level teams to discuss the focal text and choose a specific theme, moment, or topic to which they would respond. Students learned about the idea of prototyping, created multiple prototype designs, and discussed each in a critique format. Critique provided a means of formative assessment. The discussions focussed on the dynamic play among the prototypes, material choices, and the ways elements and principles of art were activated and used to convey key insights from *The Circuit*. In the evaluate phase, students staged, critiqued, and wrote responses to each group's 3D artefacts. During this process of feedback, students discussed the affordances, constraints, and tensions of fabricating response.

Participants

Participants were sophomores, juniors, and seniors enrolled in the course Teaching Social Sciences Through the Arts at a medium-sized Northeastern US Jesuit institution. Although the data generated for this project spanned both the fall 2018 and spring 2019 semesters (totaling 36 students), in this study, we focussed on a subset of students who we call lead designers. These students were not designated with this title by their peers. Instead, we use it here to signal students' continued interest in and willingness to participate in the study. The 13 lead designers were all women, 12 of

whom self-identified as White and one who identified as Black/White biracial. Given that participants were students in a course that Jon and Melita cotaught, we obtained consent to participate after submitting and releasing the final grades (see Table 1).

Data Generation

With a particular interest in examining how lead designers made sense of the affordances and constraints of 3D printing and design as a form of remediating literary response, four forms of data informed our analysis: retrospective design interviews, group compositions, planning documents, and field notes.

Retrospective Design Interviews

After the course, participants engaged in retrospective design interviews (Dalton et al., 2015). Facilitated by Jon or Melita, interviews were conducted online via Zoom. Ranging from 17 to 43 minutes in length, participants were asked about their identities as makers, arts integration as a pedagogical practice, and their design processes during the Fabricating Response assignment. During interviews, participants were shown their 3D designs and artist statements, and lead designers were asked to retrospectively respond to their compositions. Participants described their group's metamodal decision making, detailed group interactions during the project, and documented the intended purpose of their responses.

Fabricating Response Compositions

We collected material compositions—both initial prototypes and final 3D-printed artefacts—and artist statements from students. Additionally, we saved Tinkercad files, vector-based files with printer and material data that programmed the summative digital fabrication of the prints.

Ideation and Planning Documents

During the three phases of the project, participants completed a series of planning documents that helped guide their ideation and fabrication. With consent from students, we collected these documents, which helped inform the assessment of the groups' final 3D-printed compositions.

Field Notes

As instructors of the course, Jon and Melita wrote field notes after each phase of the inquiry. Although first used to scaffold, pivot, and/or revise the next instructional session's teaching, these field notes also captured themes from class discussions and major comments discussed during students' critiques.

Data Analysis

Data analysis was an iterative process in which we traced the similarities and differences between participants' compositions. To do this, we read across each

Table 1. Lead designer, title of the group's fabricated response, and artist statement.

Lead designer	Gender, race, age	Year in program	Title of 3D fabricated response artefact	Artist statement
Tiffany Suzie	Woman, white, 22 Woman, white, 21	Senior Senior	Peace?	*"The Circuit by Francisco Jiménez is an autobiographical novel full of contradictions, from the contrast of Francisco's home life to his peers to the devastating final scene. Our fabricated response to this novel highlights this theme of contradiction through a United States Immigration and Customs Enforcement (ICE) officer who has a dove over his shoulder and is standing next to a wall with the dove in the middle. At the end of The Circuit, the ICE officer shatters the Jiménez family's peace. Therefore, having a dove, which represents peace, on top of a policeman in the prominent green uniform, contradicts what occurred in the story. Another addition to the theme of contradiction is the balloon dog with a muzzle. While this dog with a muzzle may put on a front of intimidation, it is actually just made out of air. With the second structure, the wall, the dove "breaking the barrier" of the wall is a window between the worlds. Windows into other people's worlds is something we need now more than ever. Furthermore, we put our wall on the notable anti-Trump "Hate has no home here" poster, which also helps to contradict the hate experienced through the notion of a border wall. Another component of this response is the digital display on an iPad of the White House's policy on immigration, which challenges the "Hate has no home here" poster: a poster that stands against racism and intolerance."*
Lizette	Woman, white, 20	Sophomore	Packing the Box	"When approaching this representation, we first focussed on themes within the book; the theme of education and sacrifice resonated most with us. Specifically, the dichotomy and distinction between trying to focus on education while constantly having to uproot and move. The symbolic images from the story were abundant and rich so, we tried to use these symbols to show that something is always going to get left behind in a migrant life, and sometimes, education must be sacrificed. We want people to interact with the objects and the piece as a whole to begin to understand the difficult decisions that must be made between necessities and education when constantly moving. This piece aims to get people to think critically about the hardships that students from migrant families face when trying to balance the responsibility to their family and their education."
Colleen	Woman, white, 20	Junior	What's Inside the American Dream?	"The idea to create the nesting dolls stemmed from the mystery of what lies in each successive doll. The goal of this piece is to contrast the expectations versus the realities of so many immigrants coming to the United States, while also incorporating the overall uncertainty throughout the journey. The black wall represents the intimidation of crossing over and also hides what is on the other side. The U.S. flag, Statue of Liberty and the following hidden dolls at first glance represent what immigrants hope to find: freedom, prosperity, and justice. The ICE officer represents the reality of so many migrant's journeys that come to a screeching halt after they cross the border."
Heather Leonora	Woman, white, 21 Woman, biracial (Black/White), 21	Senior Senior	Which Is the Sandwich?	"In America, the sandwich is considered one of the most popular school lunches. Children love their PB&Js and ham and cheeses. However, just how familiar is the sandwich to immigrants? This 3D-printed, multi-layered sandwich focuses on the uncertainty that student immigrants face in a new country. Specifically, the sandwich is constructed in response to Francisco Jiménez's journey as a child when he came from Mexico to the United States, as he describes in his memoir The Circuit. Since its layers are separate, viewers are free to manipulate it and create a personal perspective of an immigrant child's uncertainty."

Crystal Allie	Woman, White, 21 Woman, White, 21	Junior Junior	Playtime	"This piece explores the themes of responsibility and innocence as they interact in the life of a migrant child. We identified imagery of these themes in Francisco Jiménez's *The Circuit*, and ultimately chose an oversized work boot and a can to form the most striking visual juxtaposition of the two themes. Our goal is for viewers to question the ability to play a childhood game, like kick-the-can, when facing the adult responsibilities and worries inherent in the life of a migrant child. This piece exemplifies the constant tension between maintaining one's childhood innocence and playing a role in supporting one's family."
Cindy	Woman, White, 20	Junior	Game of Life	"Creating this piece started out as an inspiration from the board games Mouse Trap and Life. We wanted to counter the youthful and naive narratives of childhood games with the harsh realities of migrant life, and the way much of life is left up to chance. Overcoming and persevering through challenges doesn't necessarily guarantee success—the cage can still fall on top of your American Dream. Childhood games are all about fun; winning or losing bears no real consequence as soon as the game is back in the box. In this representation, however, the game cannot be put away."
Rose Barbara	Woman, White, 22 Woman, White, 21	Senior Senior	Chaining Me to Them	"Our group chose to model the theme of perception versus the reality of migrant identity with a wall figure inspired by Francisco Jiménez's book *The Circuit*. The wall figure is intended to speak to contemporary invective against immigrants in the United States in order to bring *The Circuit*, which was written in 1997, into conversation with current issues. We chose to represent contemporary perceptions of migrants on one side of the constructed cardboard wall; we covered this side in dark paper on which we verbalized stereotypes against immigrants as a group of people. The other side displays the reality of a vibrant migrant identity through symbols of Francisco Jiménez's individual life, which we drew, made, and pasted using paper, markers, glue, and stickers. Between the two sides is a human figure intended to represent navigation between stereotypes and immigrants' true, individual lives. We painted the perception side of the figure in shadowy colours, but the paint is not neat or exact to demonstrate the imposition of perceptions on the individual. The other side of the figure is multicoloured to represent the multifaceted identity of a real migrant. On the foot of this individual is a 3D-printed chain with a weight on the perception side. This is intended to convey that negative perceptions weigh on immigrants and may hold them back. Overall, our goal for this piece is for the viewer to experience the contrast between contemporary invective and stereotypes against immigrants and the storied reality of immigrants' vibrant individuality, as seen through the lens of Francisco Jiménez's narrative."
Jennifer Annie	Woman, White, 22 Woman, White, 20	Senior Sophomore	Is Education Set in Stone?	"This piece was created out of recognizing the tragic reality of immigrant students in schools today. The desks, chairs, and books, printed with a 3D printer, show a typical classroom. The white walls symbolize a childlike innocence that is contrasted with the dark blue furniture, blackboard, and red writing on the askew desk. The colours are intended to contrast the innocence of children with the injustices surrounding deportation and immigrant status in America. The goal of this work is to shed light on the discontinuity in education that many immigrant students face along with the fear of deportation."

project's artist statement and generated open descriptive codes (Miles & Huberman, 1994) based on the group's goals and intentions. Every group project represented unique combinations of in-class discussions, *The Circuit*, and awareness of immigration issues in the United States. As a result of our open-coding process, we noticed that each group had different approaches to constructing imagery and engaging viewer participation. For example, some participants took a literal approach to imagery (i.e. recreating moments and scenes in the text), whereas others responded to *The Circuit* by taking a more abstract approach (i.e. employing signs and symbols to convey broader themes of the novel). In considering viewer interaction with their compositions, some participants imposed closed, static readings of their piece that asserted a single interpretation of their artwork, whereas others invited open, active audience participation to engage with their artwork and contribute to its meaning.

After establishing "literal imagery," "abstract imagery," "open participation," and "closed participation" as primary codes, we needed a heuristic to think about the compositions in ways that acknowledged the nuance of each piece beyond binary categories. To do this, we considered how imagery and participation were continua that encompassed gradations of compositional choices. Thus, we created an analytic tool (see Figure 1) to graph each composition along a continuum of open/closed viewer participation on the *x*-axis and a continuum of literal/abstract imagery on the *y*-axis. Our resulting heuristic had four quadrants of response: open/abstract, open/literal, closed/abstract, and closed/literal.

To investigate what mediational supports and constraints existed for participants when fabricating responses (research question 2), we returned to design interview transcripts, field notes, and other in-class artefacts. At this stage, we engaged in
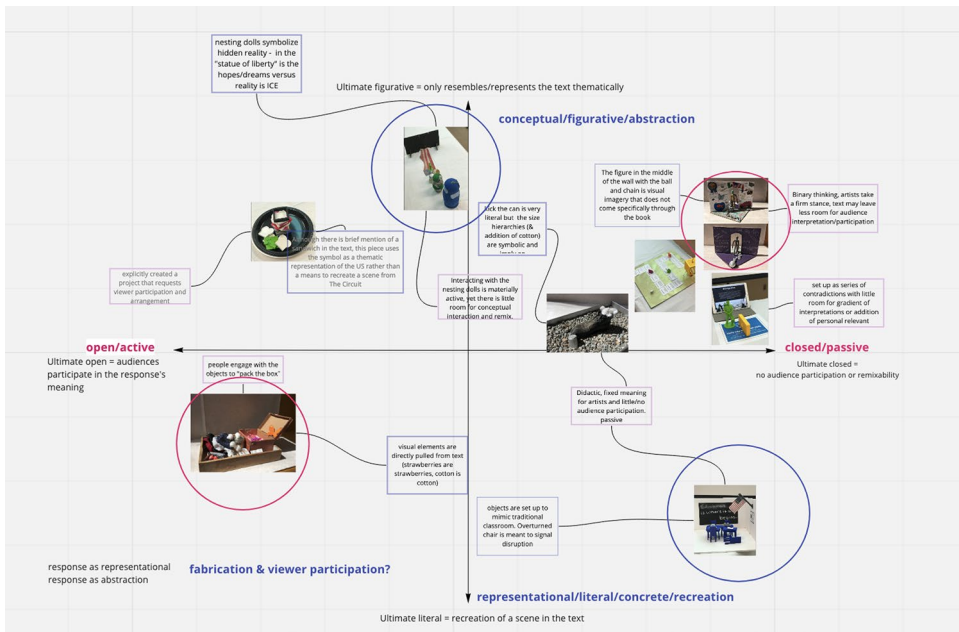

Figure 1. Analytic tool.

an analytic retroduction process (Ragin, 1994). Analytic retroduction highlights the interplay of engaging both inductive coding (i.e. codes derived from data) and deductive coding (i.e. codes derived from research questions, theoretical/conceptual framework, presuppositions concerning data). Concurrent to coding, we independently created analytic memos to help develop tentative ideas about categories and relations (Emerson et al., 1995). We triangulated these focussed secondary analyses with previously analysed artefacts and documents collected in the course.

Being-in-Relation-With: A Note on Positionality

Recognizing how we (Jon and Melita), as teacher educators, shaped the conditions for learning, here we detail who we are and how we remain in relation to this work. Jon is a gay, cisgender, white-passing, multi-ethnic (Latino/White) professor. A former kindergarten teacher and mixed-media artist, he has thought deeply about how humans encounter the more-than-human world through material composition and sensory creation. As a multi-ethnic (Costa Rican/Jewish) daughter of an immigrant to the United States, Melita has felt the sociopolitical weight and lasting effects of immigration rhetoric and systems within her own family. Currently a postdoctoral fellow, she was a doctoral candidate at the time of this study. Given her years as a practicing art educator and artist, she cotaught with Jon during the study, bringing her research on transdisciplinarity and anti-coloniality to the course. Alex, a doctoral candidate, is a White, cisgender teacher educator and former English language arts teacher. Interested in multimodal composition and literary response, he was brought on to assist in analysis.

Recognizing the diversity of experiences we brought to the study, and the issue of immigration more broadly, we regularly conversed about our readings of interview transcripts, artefacts, analytic memos, and other data sources. We noted dissonant and resonant meanings as we came to be in relationship to the work through shared discussion. Despite our intentions to forward dynamic forms of justice and equity throughout the focal assignment and course, through our reflexive practice, we also recognized moments that we would change, moments that may have perpetuated and reproduced existing oppressions in the classroom.

Findings

In this section, we address findings related to both of our research questions sequentially. First, we detail how participants leveraged design and fabrication to respond to both *The Circuit* and larger issues of immigration. This extends to how participants considered engagement with their imagined audience through response.[5] Then, we address our second research question. We talk across larger design themes and detail the material and ideological supports and constraints of the assignment. Ultimately, we suggest that remediating response through digital fabrication and 3D design yielded insight into the ways PTs navigated social issues—as refracted through children's literature—and collaborative composition.

Designing Discussion through Fabricating Response

Considering Viewer Encounter: Open/Closed

Reading across projects, we found that students' final responses were both engineered objects and relational encounters. For some of the artists, the encounters were intended to be cogenerative with the viewer, leveraging design to extend the possibilities for discussion and interpretation around their chosen theme. For other groups, the viewing relationship was more directional, meant to impart specific meaning generated by the creators.

In a project titled "Packing the Box" (see Figure 2), the group created a response soliciting viewer participation and interaction. The artists sculpted story elements from *The Circuit* and placed them in a sturdy wooden tray next to a small constructed suitcase. The items in the tray included strawberries, grapes, a 3D-printed book, a 3D-printed butterfly, a small stack of folded clothing, coins, and puffs of cotton. The fruit and vegetables were rendered representationally in color and form, whereas the butterfly and books were 3D printed in monochrome. All tray elements were objects and symbols in the text that portrayed the main character's work, school, and family life. Viewers were encouraged to interact with the objects in the tray and choose what they wanted to pack in the suitcase. Given the size of the suitcase, viewers could only pack a limited number of objects.

Figure 2. Packing the box.

The group's artist statement articulated that their piece highlighted how Francisco negotiated tensions between pursuing education and constantly having to uproot and move with his family. Specifically, the group wrote that they wanted to show that "something is always going to get left behind in a migrant's life, and sometimes, education must be sacrificed." The open suitcase became an invitation for viewers to consider their own experiences and priorities as they physically packed the box. The form and significance of the piece emerged and changed as each viewer (re)shaped the composition. When interviewed, Lizette (all names of participants are pseudonyms), the lead designer for the group, commented that "the idea [was] that the viewer would interact with the object, and they would have to try to pack the suitcase and make the decision of things to leave out of the suitcase, what *they* had to leave behind." Here, Lizette demonstrated the capacity for the interaction with her group's response to be a moment of learning and unlearning. As detailed in *The Circui*t and constructed through this group's composition, there were material constraints. For this reason, "Packing the Box" invited an open response in which viewers were active participants in the interpretation and construction of the final piece.

In contrast to the participatory elements of "Packing the Box," a project titled "Chaining Me to Them" exemplified a more closed response that limited audience involvement. This project featured a miniature human figure crossing through the threshold of a wall. One side of the wall was painted with vivid colours and adorned with various symbols (e.g. the flag of Mexico, a chalkboard, a goldfish) and materials (e.g. a first-place medal, 3D-printed butterflies) that were significant to Francisco and his family in *The Circuit*. The other side of the wall was painted in dark purple and covered with derogatory words and stereotypes against Mexican migrant workers. Along the ground, stretching across both sides of the wall, was a 3D-printed ball and shackle. The creators of "Chaining Me to Them" explained that the goal of the piece was "for the viewer to experience the contrast between contemporary invective[s] and stereotypes against immigrants and the storied reality of immigrants' vibrant individuality, as seen through the lens of Francisco Jiménez's (1997) narrative." Thus, the transition across the wall symbolized how Mexican immigrants encounter assimilation and racism during their journeys to the United States.

During our analysis, we coded elements of "Chaining Me to Them" as "binary," and "noninteractive." For example, the title of the piece contained a me/them binary, and the artist statement detailed dichotomized themes of perception/reality and stereotype/individuality. Because the audience had limited opportunities to engage with the piece in dynamic ways that interrogated the complexities and precarities of assimilation and cultural preservation, we plotted the project along the "closed" end of our continuum of audience participation.

Recognizing that audience participation is a spectrum, we categorized a third project, "Game of Life," as a semi-open response that both invited and constrained viewer engagement (see Figure 3). "Game of Life" resembled children's board games, such as Mouse Trap and Life. This game was designed on gold paper, recalling the imaginative vision Francisco had of the United States: "People there sweep money off the streets" (Jiménez, 1997, p. 3). Glued on top of the board was a pathway created by a series of squares with text directives printed on them. The text gave directions for game play, such as "A family member is deported. Move back six
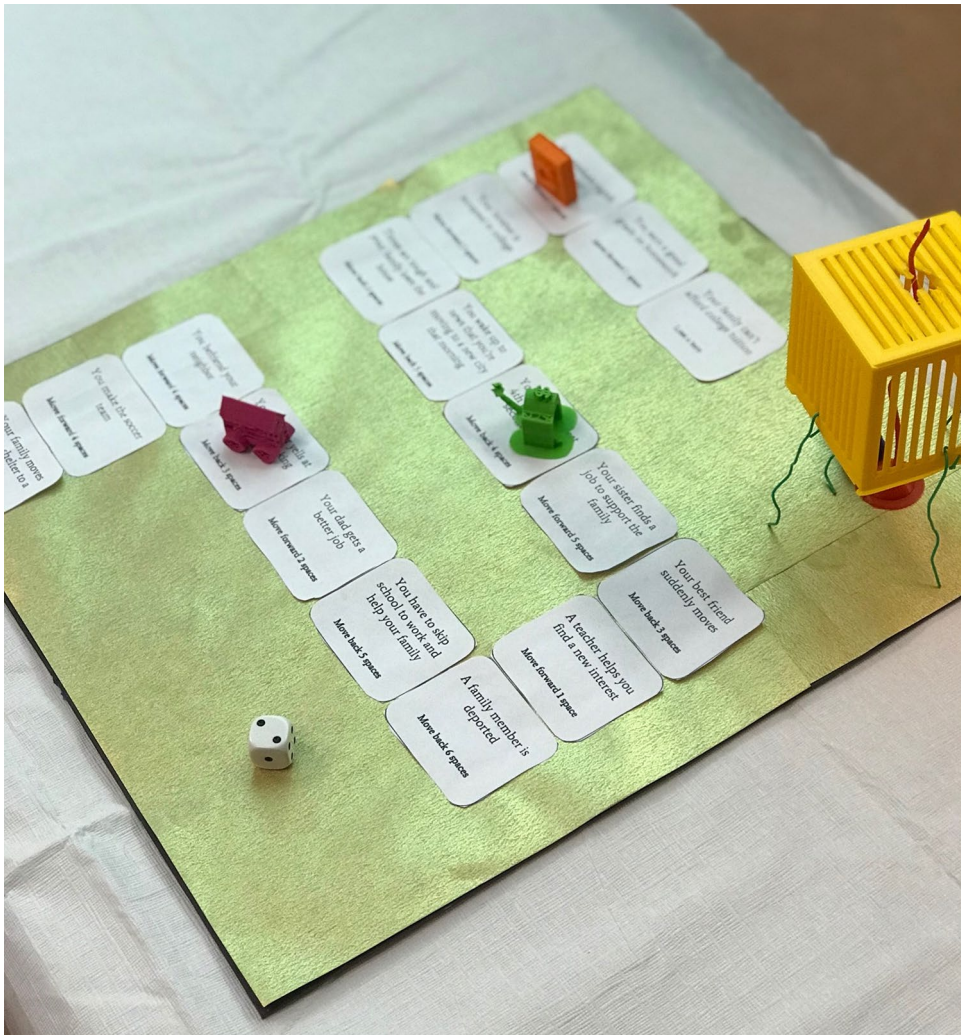
Figure 3. Game of life.

spaces," and "Your sister finds a job to support the family. Move forward five spaces." Each square recalled specific events in *The Circuit*. At the end of the pathway was a precariously perched, 3D-printed yellow cage with thin floral wire and a red spire. Cindy, the lead designer for the piece, explained, "At a certain point, it becomes impossible to win the game. But if you somehow land on just the right squares to make it to the end, waiting for you is the trap that falls." The end of the board game parallels the end of *The Circuit*, when Francisco is trapped and abducted by an ICE officer.

Although the dice and playing pieces allowed viewers to play "Game of Life," the composition had a predetermined outcome, so it was impossible to win the so-called game. The results were limited to the hardship and poverty experienced by Francisco's family in *The Circuit* rather than alternative futures for immigrant families. This means that in addition to constraining participants' play with the work, the game also

constrained the narratives students could tell and, indeed, imagine about the immigrant experience.

Elements of Visual Imagery: Abstract/Literal

In addition to thinking across the dynamism of audience reception and participation, we also analysed participants' compositions across elements of visual imagery. Whereas some compositions used imagery quite literally (e.g. constructing tableaux that mirrored scenes), others used abstract imagery that thematically linked to *The Circuit*. Here, we detail how participants' compositions featured a range of literal and abstract imagery in their fabricated responses.

A project titled "What's Inside the American Dream?" was perhaps the most abstract fabricated artefact in our data corpus (see Figure 4). The composition contained nesting matryoshka dolls to create a visual metaphor complicating the many presupposed promises of immigration. Colleen, the lead designer, suggested that the nesting doll image was reflective of the many "layers" her group discussed when examining the "mystery of migration." In her retrospective design interview, she said, "So, [the
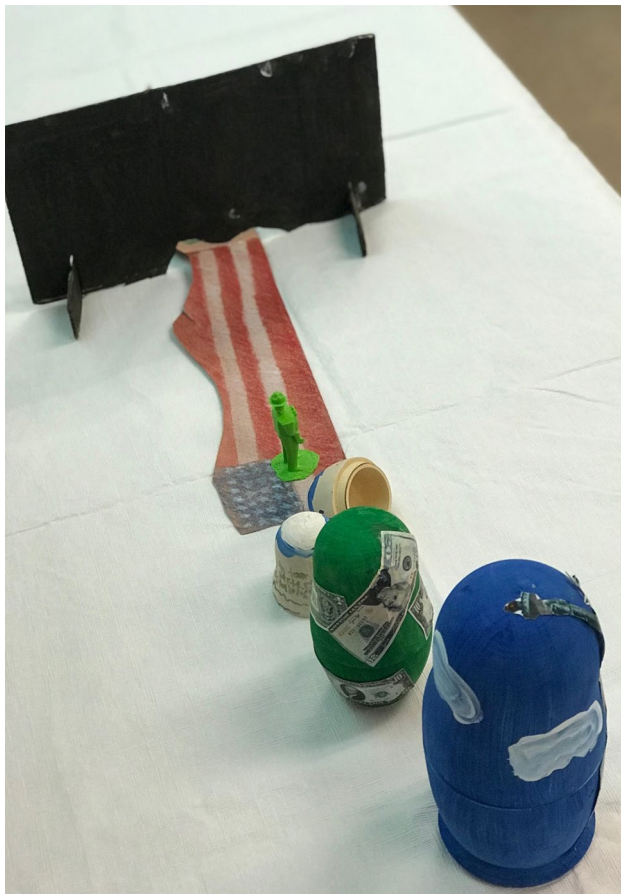
Figure 4. What's inside the American dream?

dolls represent] the Statue of Liberty, money, the Constitution, and things we associate with the American dream. … I think our idea was to show that there's much more hardship than that."

To this end, Colleen's group made the final layer of the nesting doll a 3D-printed ICE officer. This artefact functioned as a metaphorical investigation into the social issues of immigration that occur in both *The Circuit* and contemporary migration stories.

Comparatively, we plotted a project titled "Is Education Set in Stone?" on the opposite end of our visual imagery spectrum. Static in form and presentation, the piece portrayed a classroom scene that included a number of material artefacts: a paper US flag, four blue 3D-printed chairs, matching printed desks, three gray 3D-printed textbooks sitting atop the desks, and a paper blackboard with "Education is where it begins…" written in faded white chalk. Mirroring a snapshot of Francisco's life in *The Circuit*, this artefact portrayed a scene in Chapter 12 when Francisco is removed from his classroom by an ICE officer (visually represented by a toppled 3D-printed chair).

The artist statement for "Is Education Set in Stone?" asserted, "The goal of this work is to shed light on the discontinuity in education." Discontinuity, a central theme of the book and our class discussions that semester, became a concept the group wanted to illustrate. This, however, became difficult because many on the team strove for realism in their designs. Annie, one of the lead designers, recounted, "I got my mind on what [does] the classroom look like and all of the things that should be in a classroom. I wanted it to look realistic." Another lead designer from the group, Jennifer, highlighted how the group's goal for the fabricated classroom scene was to forward conversations concerning migration more broadly. Still, the 3D-printed snapshot adhered to the fiction of Francisco's singular experience in *The Circuit*.

In comparison with the previous two projects, the "Playtime" piece straddled across domains of abstract and literal imagery (see Figure 5). The composition featured a

Figure 5. Playtime.

3D-printed work boot stuffed with cotton on gravel terrain. In front of the boot was a student-made can, harkening back to scenes of Francisco playing kick the can in *The Circuit*. Crystal, a lead designer, said,

> We were talking about how we didn't want to construct a school. It just didn't seem doable at first to us, which it ended up being doable for other people, but … that kind of shifted us into more symbolic thinking.

Visually, the culminating composition represented the labour of migrant fieldwork. Although recognized by those who read *The Circuit* as a literal representation of Francisco's boot and the gravel yard in which he played kick the can, the composition also operated abstractly. The artists played with size and scale hierarchies to underscore themes such as childhood, mobility, and family responsibility. The static scene, in all, suggested a halted dynamism that was otherwise in tension with a playful reprieve of the kick the can game.

On the one hand, Fabricating Response, as an assignment, asked students to grapple with social and economic issues and cultural tensions presented in *The Circuit*. As our analyses pointed to, however, the assignment also functioned as a problem-solving space wherein students were able to discuss how their responses were imbued with personal stances regarding broader social issues. As students went through the stages of exploring, engaging, and evaluating, they grappled with how to communicate their understandings of and remediate their responses to themes of im/migration. In addition to responding through materials and 3D printing, we also encouraged participants to consider their peers as viewers and meaning makers within their processes. The resulting continuum of material responses from literal to abstract and from open to closed audience participation demonstrated the range of perspectives present in the sociopolitical environment of the classroom. Whereas some compositions (e.g. "Packing the Box") invited viewers to make sense of Francisco's childhood through a multiplicity of responses, other compositions (e.g. "Chaining Me to Them") offered a more prescriptive, binary rendering of *The Circuit* and contemporary issues of im/migration in the United States more broadly. Framing work through a continuum versus distinct categories also supported our efforts to dispute the limitations of distinct dichotomies (something being either open or closed), open to the complexity that renders binaries—both for our analytic purpose and the framing of social issues— as prematurely foreclosed and insufficient.

Mediational Affordances and Constraints of Fabricating Response

3D fabrication and computer-aided design (CAD) technologies were new tools for participants. They required instructional opportunities to gain confidence and familiarity with the process and materiality of design. In addition to analysing the fabricated compositions, we also returned to participant interview data to investigate what, if anything, acted as mediational supports and constraints in students' design processes. In this section, we detail the affordances and constraints of learning to respond through material fabrication across two domains: ideological and material. Although separated here for ease of description, we found that the ideological and material dimensions of design were intertwined and equally informed the design process.

Ideological

During interviews, participants claimed that the Fabricating Response assignment was a scaffolded, innovative medium for transmediation between text-based imagery and mixed-media literary response. The fluid stages of design and the process of interpretation, ideation, experimentation, and iteration made ideological pluralism (among group members) explicit and dialogism (among classmates) necessary. Pedagogically, critique became a mediational affordance in fostering groups' understandings of their 3D-printed artefacts beyond their personal interpretations. Rose, for instance, reported, "I liked critique. I thought that was really cool to see how other people interpreted your piece, as well as how you interpreted other people's, and also seeing it from a prototype stage to the end stage." Similarly, the "Playtime" team highlighted how in-class critique served as an instructional resource that helped advance meaning and message. Crystal detailed,

> We thought: Oh, we should stick pennies and cotton and that book that he kept all in the box. Then … I remember [our peers] talked about how powerful it was just to have, like, two things and to play with the size. So, that is kind of how we zoned in on just a very simple but powerful piece. … Through critique, we realized that the boot and the can were really striking to people. They resonated with it.

Critique, as participants suggested, was a generative pedagogical space that engaged them in attending to their peers' perceptions. It allowed for a back-and-forth between creators and viewers to advance new understandings regarding responses to both *The Circuit* and immigration policy.

As a bounded activity and assignment created by us, Fabricating Response also became a space to articulate individual ideas and work towards a shared vision for the work. For instance, Tiffany, a lead designer, said,

> It was really interesting to do an art piece collaboratively because everybody came together. We were like, "Okay, we all have these [individual] ideas, but they're totally different. How do we merge them into one?" How do you do that and still kind of capture and make people feel like they're a part of it?

For Tiffany and her group, the 3D-printing and design process fostered a synergy of interpretation and literary response. Individual members of her group came to the task of prototyping with divergent ideas. Through discussion, they arrived at a synthesis and composition that reflected their group's thinking.

Other groups, however, such as the "What's Inside the American Dream?" group, took a more utilitarian approach to their design. For this group, coming to ideological consensus, particularly with regard to immigration policy, did not always take precedence during their composition process. Rather, the focus was on satisfying assignment expectations. Even further, the group actively avoided ideological conflict among the team members. Recounting these negotiations, Colleen reported,

> I remember someone said something that I didn't totally agree with about immigration, like something about how we (the United States) shouldn't take everyone in. … It's an interesting context, particularly in your class, because we're talking about these difficult issues, and then you get [into] a group with your peers, and it becomes a little harder to have those real conversations.

As highlighted in this excerpt, Colleen observed the promise and precarity of group-oriented design. These responses led us to wonder if the affordances of design helped participants reach consensus or if the pressure to form a summative composition allowed only an approximation of the group members' opinions in service of completing the class assignment.

Fabricating Response was intended to elicit student discussion about immigration stories and policy by connecting Jiménez's (1997) story, as well as the children's books we read, with what was populating the current news. Yet, given the demographics of PTs at our institution resembled those of educators widely as they were predominantly White and middle class, there was not a range of personal experiences with immigration that brought multiple perspectives into the dialogic encounter in ways that might have allowed PTs to challenge or counter one another's ideas. This is not to say PTs could not embrace a range of understandings. Instead, it did not occur through personal storytelling or referencing the many texts we had read. In fact, the focus on learning 3D-printing processes may have occluded deeper investigation into topics of immigration, inadvertently reinforcing ideas that students held about immigration experiences and stereotypical portrayals of immigrant life. As teachers of the course, we understood this as a limitation of the study and a challenge that required rethinking on our part in designing the learning environment and curricular resources.

Outside of interpersonal supports and constraints, the sociotechnical dimensions surfaced tensions among group members and with the technology. In the Fabricating Response project, PTs visualized and verbally discussed ideas as a group and then engaged in modelling and prototyping with cardboard, drawing, and digital software. In reflecting on their final 3D-printed objects, PTs discussed the affordances and constraints of learning to respond through material fabrication and how the compositions were always already informed by particular signs and signifiers (e.g. a boot representing adult's work, a cotton ball representing cotton picked from a stalk in a field) that were connected to previously held ideological assumptions.

Material

Participants' lack of experience with 3D design and digital fabrication initially limited their ability to envision integrating this work into their future classrooms (see Figure 6). Rose, however, described how her comfort with 3D printing grew over time:

> We 3D-printed that ball and chain, which was super cool. It turned out so much better than I thought it was going to. I think that really stuck out to me. When you first assigned it, I was like, "I don't know how to work a 3D printer. I won't be able to do this." … So, actually getting that experience with it was really cool, and being like, Okay, this is actually really easy to use, and this is something I would be comfortable showing somebody how to use.

3D printing allowed Rose to build her project from ideation to material reality. Additionally, through the opportunity to learn how to use a 3D printer in class with technical support at each phase, the participants became more comfortable with the idea of apprenticing other educators and students into 3D printing as a medium for communicative responses.
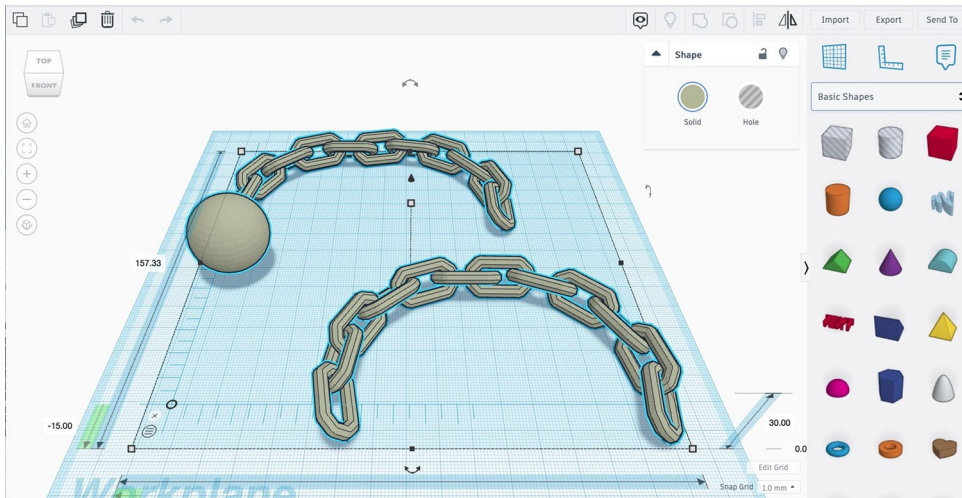
Figure 6. Chain STL file.

This increased level of comfort with 3D printing also changed some participants' criticism of digital design. Whereas some students initially characterized 3D printing as inaccessible, intangible, and daunting, the project helped them see more potential in the medium. Leonora, for example, stated, "I think seeing the accessibility of things, especially with 3D printing, it is such a cool thing to make your ideas into a physical form that you otherwise wouldn't be able to do." The opportunity to experiment and test out ideas for fabrication was critical for weighing these experiences against preconceived notions of 3D-printing technology.

Some participants, however, expressed frustration with the 3D design process. Given that the initial 3D design work was done in online modelling software, some participants struggled with not being able to grasp, bend, fold, or otherwise manipulate materials with their hands. One of the lead designers, Heather, made comparisons to different materials we used in prototyping:

> With the pipe cleaner, you can move it with your hand, whereas the 3D printing, we had to play on the computer first. It wasn't as hands-on at first because we couldn't morph it into what we wanted so easily.

In other groups, too, the initial intangible nature of 3D printing, primarily the lack of physical manipulation, "felt a bit limiting," as they struggled to make the final piece match their vision.

For other PTs, their connection to the fabrication process seemed out of touch with the topics they were addressing. Allie, a lead designer, attested to this when highlighting her group's overarching goals for the project:

> We were trying to respond to this very polarizing, relevant issue in a way that made it seem like we weren't just making it a fun art project. Like, we wanted to give it the depth that it needed. … So, I think we struggled with that, in being able to actually have our ideas manifest through 3D printing.

Communicating an idea, through any material, can be a challenging iterative process. Allie highlighted her group's desire to create meaningful work that reflected the

serious nature of immigration in the United States and, more specifically, of Francisco's journey in *The Circuit*.

Finally, PTs observed some of the challenges we had to address with the functioning of our own 3D printer during the course. Tiffany drew parallels between our constraints and her own school's use of 3D printing:

> Our Parent–Teacher Organization, without the permission of the district actually, purchased a 3D printer. And as you've learned, it just breaks all the time. Nobody knows how to use it, and they've now updated the laptops, so nobody even has the program to plug into it.

Tiffany, as evinced in this excerpt, picked up on a constraint of being able to integrate 3D printing into the classroom. As she highlighted, the tools and technology need maintenance and compatibility across platforms, which may require collaboration among seemingly siloed departments at schools.

The material affordances and constraints, just like the more ideological tensions and supports, offer insight into what is necessary in setting up the conditions for successful 3D-printing projects. Both the technology itself and the participants' technological familiarity impacted how they felt about the process, what they believed was possible in their compositions, and, indeed, the remediation of their responses.

Discussion

In this study, we examined how 13 PTs in the course Teaching Social Sciences Through the Arts remediated responses to Jiménez's (1997) *The Circuit* through 3D printing and arts-integrated making. Qualitative analyses revealed participants' navigation of ideological and material supports and constraints during the digital fabrication process. As a result, reading and responding to text—as mediated actions and events—became iterative spaces wherein individual understandings of text transformed into shared encounters of difference. These findings not only support and advance current work in reading and remediation but also underscore the need for and potential in cultivating more multidimensional understandings of individual and collaborative multimodal responses. Notwithstanding, we also recognize that these analyses are limited. Next, we detail these limitations while forwarding a more nuanced understanding of fabricated response as critical literacy.

A central limitation of this study, like other investigations rooted in sociocultural traditions of literacy (see, e.g. Smagorinsky & O'Donnell-Allen, 1998), is that we do not know participants' prior histories of participation and social actions or how these histories informed their responses to the specific context of the classroom or the broader social issues under discussion. Similarly, and given that the work we describe here was captured across three in-class sessions and retrospective design interviews, we cannot make claims regarding the action or processing that happened in the interim of in-class sessions. As such, we—as researchers—were left to make inferences based on the data collected (e.g. interviews, artefacts). Our analyses, although based on transcripts of individual interviews, artist statements, and collaborative design interviews, do not account for developments in student thinking. Hence, the analyses are incomplete and, given Jon's and Melita's positions as instructors, potentially biased. In short, we are limited by our own imagining and describing of the Fabricating Response assignment.

Despite these constraints, our analyses point to the complex and complicated ways participants designed their responses to *The Circuit*. For PTs, fabricating response was an interpretative process whereby social and cultural values and practices were remediated into 3D artefacts. These interpretations—the illustrative frames of scenes and themes—however, were partial. Participants read about Francisco's life, and immigration more broadly, through their own experiences and positions in social worlds, a process made evident in asides and the rich descriptions found in interview transcripts and artist statements. Like others interested in the way multimodality, remediation, and arts-integrated response may better elicit students' responses to text, our analyses point to the way reading and designing are mediated processes.

Fabricating Response was imbued with material and ideological resources that, ultimately, were ushered forth through semiotic systems of mode and meaning. Hence, our study points to the power and potential of taking a multimodal approach to literary response. "Rather than taking talk and writing as a starting point," as Jewitt and Kress (2003) asserted, "a multimodal approach to learning starts from a theoretical position that treats all modes as equally significant for meaning and communication" (p. 2). Studies focussed on 3D printing as an instructional technology often prioritize functionality, placing value on the printed object as a way to fix or create a designed solution to problems. In contrast, the Fabricating Response assignment focussed on a critical and creative read, an expressive transaction between *The Circuit* and the reader, by leveraging objects as "things to think with," artefacts for negotiating and exposing "hidden assumptions and values" (Ratto & Hertz, 2019, p. 26). Notably, the making of art was not subservient to the literary text or the social studies content in the course. Rather, art making amplified the communicative possibilities made available through technology.

Through the Fabricating Response assignment, we created the opportunity to move beyond the representational to the abstract and consider and involve the viewers' perspectives in participants' meaning-making processes. This happened both during group members' convergence on a design idea and through formative and summative critique and exhibition. As Cope and Kalantzis (2009) argued, designing "is something you do in the process of representing meanings—to oneself in sense-making processes such as reading, listening or viewing, or to the world in communicative processes such as writing, speaking or making pictures" (p. 175). Movement between group discussion and class discussion surfaced differences among students regarding their sociopolitical engagement with immigration. As Colleen noted earlier, students moved from a more familiar group discussion space to intimate small-group discussions, where in order to come to a consensus on a printed object, participants had to express their ideas and, potentially, unearth personal biases and ideas about immigration. Discussion also highlighted the differences between Francisco's world and the world of participants.

Whereas the final object is central to elucidating this difference, what remains critical to the social environment of the classroom is the awareness that such differences exist in a pluralistic, dialogic society. As static as they may seem, these artefacts point to the power and potential of reading multimodal responses as critical literacy texts. Many compositions ignited what Greene (1995) called the "social imagination: … invent[ing] visions of what should be and what might be in our deficient society,

on the streets where we live, in our schools" (p. 5). Operating as critical literacy texts, fabricated compositions became palimpsests for reading how power can be reconfigured for a more equitable social order and just future.

Conclusion

"Reading and composition," as Smagorinsky and O'Donnell-Allen (1998) contended, "are those processes that are derivative of prior situated processes and in turn generate representations that themselves potentially serve as the springboard for continued acts of representation" (p. 221). Constructed responses, in other words, are but one of many interpretative texts through which one can begin to understand a reader's reflective thinking. Taking this one step further, one can understand how art and arts-integrated responses operate as what Freire (1983) would have called a "rewriting" of the social world. Kress (2010), too, wrote of this perceptual capacity when he detailed how design, as a political endeavour, is "the process of translating the rhetor's politically oriented assessment of the environment of communication into semiotically shaped material" (p. 132). Although not to the scale of JR or other artists featured in the introduction of this article, our research confirms these sentiments in highlighting how participants read the word world of *The Circuit* to rewrite and remediate multimodal responses. Thus, reading, understood here "as a political act, an act of knowledge, and … as a creative act" (Freire, 1983, p. 10), and responding became complex processes exhausted not by searching for one meaning but rather by extending more consequential knowledge into the world.

Notes

1. From Dewey's (1934) early advocacy for aesthetic learning experiences to more contemporary work suggesting that the arts allow for rich combinations of form and meaning that expand what learning can be (see, for example, Halverson & Sheridan, 2014), the argument for bringing the arts into other disciplines has a long history. School-based arts integration has elicited debate for three reasons: (1) binary arguments for the effects of arts-integration tend to foreground their instrumental value (i.e. helping students succeed in the academic discipline) or their intrinsic value (i.e. because art supports students with socioemotional learning and self-expression; Gaztambide-Fernández, 2013), (2) integration can result in an oversimplification of the arts and reinforce long-standing academic hierarchies among disciplines (Mejias et al., 2021; Peppler & Wohlwend, 2018), and (3) arts integration does not consider underlying notions of how the arts shape activity (Gaztambide-Fernández et al., 2018).

2. Dominant framings of arts education (and what it means to be an artist) have been shaped by values and aesthetics dating back to the Renaissance, conceived (and then exported) on Eurocentric terms. Gaztambide-Fernández et al. (2018) wrote that "'the arts' and what it means to be an artist are profoundly shaped by racial logics and racist assumptions" (p. 2) implicitly predicated on Eurocentric understandings of cultural production and sophistication. Given our focus on sociocultural theories of learning, we looked to expand pedagogical possibilities by taking up the arts as forms of cultural practices involving symbolic creativity (Gaztambide-Fernández, 2013). We were committed to what was made possible through engaging in digital technologies and additive manufacturing, repurposed for non-entrepreneurial and expressive means.

3. 3D printing—an emerging technology that facilitates the creation of objects through material design—has become a powerful educational tool (Elrod, 2016; Ford & Minshall, 2019;). 3D design and printing asks composers to perform semiotic work differently. Polylactic acid—the thermoplastic used in 3D printing—brings with it different potentials for meaning making (e.g. density, color) and so too does the software that accompanies computer-aided design. Across disciplines such as secondary history (Maloy et al., 2017), anatomy (Vaccarezza & Papa, 2015), art education (Menano et al., 2019), chemistry (Gross et al., 2014), rhetoric (Sheridan, 2010), and technology education (Chien, 2017), scholarship has documented 3D printing's affordances as an innovative learning technology. However, empirical research examining 3D printing in the teacher education classroom has been relatively scarce (see, e.g. Maloy et al., 2017; Song, 2020; Verner & Merksamer, 2015;).

4. Although we rooted our study in the sociocultural tradition and operated from a logic of reflection/representationalism, alternative perspectives of thinking with materials exist. Leveraging ideas of relationality from the visual arts, science and technology studies, and philosophy, we used these more-than-human encounters with materials to examine the material ↔ discursive entanglement through the vantage point of diffraction (see, e.g. Pacini-Ketchabaw et al., 2017).

5. Fabricating Response is an activity grounded in examining how responding through materials remediated textual responses through acts of symbolic creation. PTs began with reflection and individual responses to text. Because of our grounding in sociocultural theories of learning, we were interested in how the individual responses were explained and reformulated through the discourse stimulated by the collaborative aspect of the artifact design. Similarly, final artifacts that were more abstract held a potential for further reformulation through peers' interpretation, bringing more conversation and discussion into the project. In that way, we had particular interest in nonrepresentational forms but were not evaluating the artifacts based on such criteria. Rather, in our analysis, we worked to understand the patterns across different forms of representation.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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