# 2 A Dialogical Imagination of Coding in STEM

*Quests for my own words are in fact quests for a word that is not my own, a word that is more than itself; this is a striving to depart from one's own words, with which nothing essential can be said. I myself can only be a character and not the primary author. The author's quests for his own words are basically quests for genre and style, an authorial position. —M.M. Bakhtin*[1]

## 2.1 Motivation: From Situatedness to Computational Heterogeneity

It is not difficult to trace the intellectual history of constructionism to feminist standpoint scholars who fundamentally questioned the position of knowledge as objective.[2] Rooted in the *situatedness* of knowing that stands in opposition to instrumentalist accounts of learning, constructionist approaches emphasize the construction of public artifacts (that are also personally meaningful to the learner).[3] The immediate epistemological entailment of situatedness, as Wilensky has reminded us, is that the progression of knowing is not from concrete to abstract or from the situated to the removed.[4] Instead, as we understand more deeply, the object of knowing simply becomes progressively more situated in our experiences. The abstract is the unknown, and to become known, it must necessarily become concrete. Higher forms of abstractions, Wilensky posited, mean richer forms of concretion in experience. Bakhtinian lenses of heterogeneity and heteroglossia can help us *see* this process of concretion unfold in ways that can help us avoid the technocentric panopticon.

Another entailment of situatedness is a fundamentally heterogeneous imagination of the learner. Challenging notions of abstractions in technoscience, Haraway argued that if knowledge cannot be separated from contexts—cultural, historical, and personal—then the image of *the knower as an autonomous entity* must also be challenged. Positioning subjectivity at the center of human experiences of knowing and being implies heterogeneous and emergent conceptualizations of human-technology relationships. Haraway's *cyborg* is such an emergent conceptualization in which boundaries between the human and the computer, the mind and the body, and the social and the material worlds are fluid and necessarily transgressed. Ames's critique of the individualistic trajectory of computing and educational computing must also be kept in mind in this regard.[5] This is aligned with a Bakhtinian imagination in which human acts are imagined as "text *in potentia*,"[6] that is, ongoing acts of voicing in which *thingification* and *personification* are inextricably intertwined and the "I" is in constant interrelation with the "other."[7]

We therefore argue for a shift from viewing coding as production of computational artifacts to voicing computational utterances. This shift in metaphors is, in essence, a shift away from an overt reliance on a device-centered discourse of control to expansive imaginations of heterogeneity and heteroglossia. Our concern is that despite epistemological roots in the situatedness of feminist technoscience, constructionist approaches have largely fallen short of challenging technocentrism. Somewhat recursively, our goal here is to offer the Bakhtinian lens as a set of epistemic tools that can more directly counter technocentric imaginations of computing beyond accounts of situatedness. By moving beyond objects and ownership, voicing computational utterances can be seen as an ongoing search for others and otherness. Our proposal implies a *différance*[8]—that is, both difference and deferral—of meaning, rather than foregrounding immediacy and control at the center of experiences of coding. It also indicates a repositioning of the learner from an autonomous entity to a social voice.

In the rest of this chapter, we outline elements of a Bakhtinian framing of coding in K–12 science and STEM contexts that can help us engineer these shifts. We position heterogeneity as the fundamental anchor of this Bakhtinian vision, and identify some key elements: perspectives, addressivity and alterity, and transparency.[9] While these constructs are essential to understanding a Bakhtinian view of language in a general sense, our goal here is to outline them in the context of coding in K–12 science and STEM so that they lay the groundwork for the following chapters, which in turn offer empirical illustrations of these elements of heterogeneity.

## 2.2 Voicing Code in STEM: A Dialogical Imagination

### 2.2.1 The Anchor: Voice as Heterogeneity

We begin our journey by centering our attention on the notion of *voice*. Bakhtin argued that *a* voice is an act of coming together, in the forms of hearing, speaking, and co-opting of a multitude of voices.[10] The uniqueness of an utterance is created through ventriloquation, the process by which one or more voices speak through another voice (or a voice type).[11] The voice is thus both porous

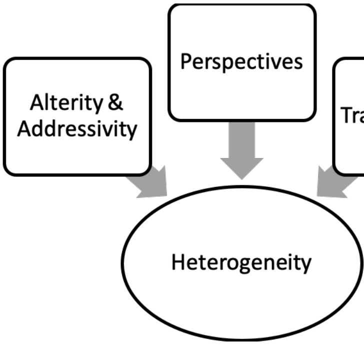


**Figure 2.1**
A dialogical model of heterogeneity.

and a whole. It is both intentional and historically and socially constrained. Voicing involves a search for words that are not the speaker's: "Quests for my own word are in fact quests for a word that is not my own, a word that is more than myself; this is a striving to depart from one's own words, with which nothing essential can be said."[12]

Understanding what *a* voice represents and how it comes to be, despite its univocal rendition in the form of what gets uttered, thus requires a manifold imagination, akin to Bakhtin's metaphor of refraction.[13] In this image, the meaning of a word emerges through an interplay of the word with the world, in a manner akin to sunlight becoming visible to the human eye through spectral dispersion in the atmosphere. That is, the color of sunlight visible to the eye emerges as the light emanating from the sun as it passes through and optically interacts with various elements that make up the atmosphere, which in turn alters its speed and direction of travel, as well as the colors that eventually are visible to us. So, what we perceive and conceptualize as a "property" or an "attribute" *of* the sun—the color of sunlight—emerges through interactions with myriad elements of the universe beyond the sun. Likewise, the intention of the word gets made and remade as it disperses through the world, even in cases in which such dispersion might be construed to happen within a speaker's mind.

For Bakhtin, a "word" is therefore much more than a symbolic object. It is a *phenomenon*—an unfolding, a "tension-filled environment," where meanings and voices compete and combine with one another. The word is not simply the *container* or *carrier* of meaning, and neither can it be "owned" by anyone. In this view, words are not neutral objects; they always belong to someone else until an *utterance* is created, and when it does become a part of the utterance, it becomes "one's own" only when the speaker populates it with her or his own intention. To quote Bakhtin, it is the *social atmosphere* of the word, refraction through which makes the word meaningful. As Wertsch points out, this is a dynamic imagination of language, in which heterogeneity of and conflict among voices is essential for understanding how univocality emerges.[14] It is also important to note that the essential counterforce to heterogeneity is aesthetics, which Holquist positioned as "the struggle to achieve a whole out of this heterogeneity."[15] This is not merely an additive force, but is rather a synthetic and transformative force, one that lends itself well to Dewey's positioning of aesthetic experience as a fundamental form of human experience. It is aesthetic experience that renders the world meaningful to us,[16] and it can be particularly helpful for advancing our critical phenomenological agenda. We return to this issue in more detail in the following sections.

A fundamental premise of our book can be stated here simply: what is true of the word is also true of code. As with the Bakhtinian utterance, we position computational utterances as elemental pieces of experience that are the sites at which the constancy, historicity, and systematicity enter into contact and struggle with unique, situated performance. This is an emergent imagination of language, in which meaning of an utterance emerges from the interactions between manifold forces, some of which seemingly oppose each other. We define computational utterances as computer models and simulations, embodied and material representations that students and teachers construct to make code meaningful. In this section, we illustrate how the lenses of perspectives, transparency, alterity, and addressivity can help us understand computational utterances.

### 2.2.2 Dialogical Lenses for Modeling Heterogeneity

**2.2.2.1 Perspectives** Our attention to perspectives arises from Bakhtin's positioning of *heteroglossia* and polyphony as essential characteristics that render meaning to any utterance.[17] However, because *heteroglossia* was a term coined by Bakhtin's English translators, its meaning itself is somewhat heteroglossic.[18] In one view, heteroglossia, or *other-languagedness*, refers to the ideologies inherent in the various social languages we partake in our daily lives, such as the language and the inherent ideologies in our professional worlds, age groups, the current decade in time; of our social class, geographical region, family, circle of friends, and so on.[19] More broadly, it can indicate conflicting discourses within any field of linguistic activity (e.g., a national language, a novel, or a specific conversation). Polyphony or *many-voicedness* refers to the collective quality of an individual utterance: by embodying other voices within itself, the utterance creates a dialogic relationship between different voices (the speaker's and the others'). As Bakhtin noted, "Every utterance participates in the 'unitary language' (in its centripetal forces and tendencies) and at the same time partakes of social and historical heteroglossia (the centrifugal, stratifying forces)."[20]

It is not simply vocabularies that distinguish the different social languages that constitute utterances; rather, as Rosebery and colleagues noted quoting Bakhtin,[21] they differ from each other in terms of "specific points of view on the world, forms for conceptualizing the world in words"[22] and as "specific forms for manifesting intentions."[23] Also, the polyphonic layering of voices that renders a novel its rich discursive character can be understood in terms of embedding multiple points of view—of the narrator, the character, and the genre—all within a single voice.[24]

The discursive complexity in STEM classrooms can also be understood in this light, as Rosebery, Warren, and their colleagues at TERC and Boston University have shown through their long-term research project focused on heterogeneity and heteroglossia in the science classroom. Their work shows how the heteroglossic nature of a novel can help us understand the discursive complexity in a science classroom. Here we borrow an example from them that illustrates the importance of points of view in understanding the fundamentally heteroglossic nature of classroom science talk around the word "cold." Heat and cold are common experiences in our daily lives, as well as commonly explored topics in the science classroom.[25] People typically use the word *cold* to refer to a sensory experience. For example, to a 3rd grader holding an ice cube, the ice cube is making her hand cold. Similarly, the word *heat* is typically used in everyday language in connotation to the sensory experience of feeling hot. To a physicist, however, at 32 degrees Fahrenheit an ice cube has a lower temperature than the child's hand; heat energy is thus transferred from their hand to the ice cube. The simple act of holding an ice cube is a complex phenomenon that also involves thinking about the pressure exerted by the hand on the ice, which can lower the melting point of ice and further complicate matters. Furthermore, in physics parlance, both *hot* and *cold* are states of matter that indicate temperature, whereas *heat* is the property of matter (a form of energy) that the temperature represents.

The difference in language use and the implied conceptualizations across these cases can be understood in light of perspectives or points of view that are in play. As Rosebery and colleagues have pointed out, a physicist's perspective offers a fundamentally different way of seeing heat and cold, a fundamentally different point of view. It brings into view a set of interactions and mechanisms of energy transfer, the notion of energy itself, and the notion of pressure. The interpretation of the experience of feeling cold or feeling hot is significantly different, as a result of these perspectival differences, from lay use of the term *cold*. Adopting a psycholinguistic approach,[26] Greeno and van de Sande[27] remind us that physicists' (disciplinary experts') perspectives rely on a set of constraints that serve as conditional relations between situation types. These constraints can be understood as properties and relations of objects and events that constitute a situation from a disciplinary perspective. Thinking about these constraints, in turn, can then offer a disciplinarily authentic way of conceptualizing the situation. Learning then involves developing such perspectival ways of thinking about the relevant phenomena.

There are, of course, several different ways in which we can conceptualize and analyze the role of perspectives in learning that scholars (psychologists, linguists, and sociologists) have long argued for. Rommetveit[28] argued that alignment of perspectives is a necessary condition for understanding the intended meanings of sentences and messages. MacWhinney[29] argued that syntactic features function to signal shifts in perspective, supporting comprehension of sentences. Talmy[30] noted that not only does our spoken language structure our conceptualization of space, but it also structures how we comprehend time. In sociology, several scholars—perhaps most notably, Goffman[31]—have greatly advanced the study of perspectives by illustrating how people's social positioning (*footing*, to use Goffman's term) shapes how they understand themselves in relationship to one another in terms of the social and cultural expectations implicit or explicit in the setting. Ackermann[32] further argues that perspective taking could involve different ways of projecting the *self-in-context*,[33] including taking on different characteristics of others in the situation.

Our point here is not to argue about the utility of some of these ways of thinking about perspectives over others. Instead, we want to emphasize that paying attention to the perspectives in which coding is enmeshed is essential for both understanding and supporting learners' experiences. This is particularly relevant in K–12 STEM classrooms, given the inherent interdisciplinarity of using computing in disciplinary contexts. It can also help us—researchers, designers, and teachers—bridge thinking about *concepts* with thinking about *activities*.[34] As chapter 3 illustrates, doing so can help us see what in a situation is really the "roadblock" for the learner, or conversely, what in the situation is worth paying attention to, from a pedagogical perspective, for bringing about perspectival coherence. After all, it is our *points of view* that decide (both perceptually and conceptually) what we notice in a situation, and understanding, as Greeno and colleagues have argued, typically requires bringing about an alignment between the multiple points of view involved in our interactions with others and the world. It is therefore no surprise that cognitive scientists have argued that both perspective *taking* and perspective *tracking* are central to human sense-making.[35] Following Greeno and van de Sande we henceforth refer to this form of thinking as *perspectival thinking*.[36] The former helps structure the constituents of mental models by linking actions to referents, and the latter helps us link our individual mental models with broader cultural understandings.

Beginning with Papert's Logo, pioneers in computing education have long argued that perspective taking is indeed helpful for learning to code, and we revisit this conversation in more detail in chapter 3. It is, however, appropriate to mention here that the paradigm of computing that we use in this book—*agent-based computing*—is rooted in Papert's vision of the learner being able to take on the perspective of computational agents (e.g., the Logo Turtle). Agent-based computing recasts any phenomenon as an interaction between an agent and elements in its environment (e.g., modeling the motion of an object as an interaction between the object and the surface it is moving along) or as interactions among multiple agents as well as elements in their environments (e.g, modeling ecological interdependence as the dynamic interaction between predators and prey in an ecosystem).[37] In either case, students and teachers interacting with the simulation and the underlying code are prompted to take on the perspectives of different agents or elements in the simulation. This allows them to dive into the phenomenon by taking on a *bottom-up* perspective and experience the phenomenon from the perspective of different agents in the system. At the same time, they are able to take on a *top-down* view by looking at the system-level, aggregate behaviors and outcomes that result from these interactions—for example, graphs of populations of different species in an ecosystem that illustrate their interdependence.

There is now a substantial body of literature that shows that adopting the agent perspective can lead even young learners to develop deep understandings of aggregate-level phenomena in multiple domains such as physics, ecosystems, materials science, chemistry, and so on.[38] While these studies primarily use students' explanations as data, there has been relatively less focus on the microdynamics of perspective taking and perspective tracking in shaping students' explanations, and what this might mean for teachers trying to support the development of these explanations. This is particularly relevant in STEM classrooms, given that multiple perspectives are involved in working with programming languages, disciplinary practices, and spoken languages, especially in collaborative settings. This is (unsurprisingly) a phenomenological agenda:

our goal is to expand and deepen our understanding of the *sense experiences*[39] of students and teachers in engaging with computing in the science classroom. As we begin to see coding as conversations between students (and teachers), the complexities of negotiating multiple perspectives inherent in such conversations offer both opportunities and challenges for engaging with the code and the simulation.[40] Chapter 3 offers an insight into such heterogeneity, and chapters 4 and 5 offer insights into forms of perspective taking that involve negotiating boundaries of the self and the other in ways that are better understood in light of *alterity* and *addressivity*, which we discuss next.

**2.2.2.2 Alterity and addressivity** Wertsch[41] presented a phenomenological account of how language is *experienced* from a Bakhtinian perspective. He argued that Bakhtin's dialogic imagination necessitates that we view language not by studying how people "receive" meanings that reside in speakers' utterances, but by focusing on how interlocutors might use texts as tools for thought and create new meanings. Wertsch also pointed out that in Bakhtin's work, central to this image of multivocality is the experience of *alterity* or *otherness*, which can be understood as the dynamic interaction between one voice and another. Bakhtin argued that it is through this ongoing interaction that utterances emerge. Clark and Holquist similarly argued that for Bakhtin, otherness is the ground of all existence and of dialogue, representing "a constant exchange between what is already and what is not yet" (p. 65).[42] To *be*, in Bakhtin's words, is "to be for the other, and through him, for oneself . . . I must find myself in the other, finding the other in me."[43]

One of the foremost scholars of Bakhtin's work, Todorov points out that in order to be understood, every representation of language must put us in contact with its utterer. This is also an experience of otherness or alterity. It is through this process of identifying *who* is speaking that we become *conscious* of language.[44] Therefore both creating an utterance and listening to one can be reconceptualized as negotiations of the boundary between the self and the other, in the same way that Bakhtin problematized the relationship between the "inside" and "outside" of text. For him, boundaries between the origin, the context or referent of text, and its form or structure are porous and fluid, and *language in use* is the heterogeneous act of negotiating these boundaries. Meaning is the coherent shape of these boundaries that emerges through the negotiation, during which elements inside and outside of the text, as well as the speaker and the listener, are in put in conversation with each other. Arguing against viewing text as authoritarian or monologic discourse, Bakhtin noted that "we evaluate our exterior not for ourselves, but for others through others."[45]

The alterity of language makes each voice a consummation of myriad voices and perspectives. Voicing and listening are nested recursively within each other, and to understand an utterance or speech we must learn to listen who are the others speaking through the speaker. An essential element of alterity is therefore the more complex situation of *reported* speech: "of speech within speech, utterance within utterance, and at the same time also speech about speech, utterance about utterance."[46] The simple presence of an addressee does not necessarily make speech dialogical; rather, it is the possibility of commenting or reporting on someone else's speech—the "active reception of other speakers' speech"[47]—that is the essence of dialogicality.

When we look at a line of code as a form of heteroglossic text and at coding as acts of forming computational utterances, many forms of the otherness become explicit and essential for working with code, particularly in the context of K–12 STEM disciplines. For example, addressivity is the inseparable other of an utterance, and pedagogical designs around coding can benefit greatly from enlivening the addressee as an integral part of designing the computational utterance. This becomes evident in chapter 4, in which coding in a math classroom becomes reframed as computational design, and we then see how paying attention to addressivity by involving the user's voice *within* the design process plays an important role in deepening students' engagement with both computational and disciplinary practices. In chapter 6, we present another illustration of alterity, which begins with imagining how a line of code is represented in different forms as part of a computer model in a science classroom. Simply put, a line of code can be represented *within the computational model* as a string of programming commands, comments within the code explaining the meaning of the commands, and visualizations in the form of simulations and graphs. However, teaching and understanding the mathematical relationships represented by the code may necessitate the use of other forms of modeling, such as embodied and physical modeling. Coding, especially in the K–12 science classroom, is not merely the act of creating a computer program that compiles and generates the desired output. It is, instead, a heterogeneous and heteroglossic language that integrates materiality, discourse, and embodied interactions outside the computer with the symbolic world that constitutes the computer model. Code and its *other*—which at the broadest level, is the world outside the computer—are thus deeply intertwined in experience, in the K–12 science classroom, and we will see several images of such alterity in the empirical chapters.

The otherness of code can also play an important role in a critical phenomenological sense. Critical phenomenology points to the ways in which "experience" is not universal; instead, we must learn to recognize how some voices and ways of knowing, feeling, and perceiving are privileged but others tend to be silenced or excluded, particularly in disciplinary and institutional settings.[48] Prominent feminist and post-structuralist critiques of technoscience have identified technological determinism[49] and masculinist notions of a "pure" discipline[50] as deterrents for equity in cultures of computing. At stake here is what should count as code and coding, including possible imaginations of what computational design and computational science can look like in professional practice as well as in the K–12 classroom. A particular critique of technological cultures that we build on in chapter 7, for example, is how relational work—the essential act of caring for, and helping others in complex technology design projects—is institutionally devalued in favor of reifying the myth of individual accomplishment through abstract and reductionist measures of efficacy.[51] Another form of disciplinary expansion is evident in chapter 5, where we consider how computational agents could stand in as *transitional others* and enable preservice teachers to engage in difficult conversations about race and urban segregation in the US. Race talk can become code talk, and relational work can deepen children's engagement with computational work.

**2.2.2.3 Ambiguity and transparency** Central to our discussions on perspectives, alterity, and addressivity is the repositioning and reimagining of the human-machine boundary by challenging the orthodoxy of the persistent vision of computing that restricts studies of learning and computer-human interaction to device-level engagements.[52] Haraway's *cyborg* can now be understood as an example of Bakhtin's notion of *hybrid construction*.[53] The boundary between the human and the computer is fluid because, in Bakhtinian parlance, one voice speaks through the other. The metaphorical image here is of intertextuality rather than the literal caricature of a robotic voice ventriloquating through a human. Todorov[54] and Kristeva[55] argued that Bakhtin's "dialogism" and "polyphony" are forms of *intertextuality*, which was defined by Kristeva as follows: "Any text is constructed as a mosaic of quotations; any text is the absorption and transformation of another."[56] If we are to locate the ambiguous boundary between human and computer languages in the intertextuality of code, it follows that we must learn to pay close attention to absorptions and transformations that result when computer languages come in contact with human discourse.

A closer look at the nature of representational work of scientists reveals similar ambiguous boundaries between ideas and the world. Pickering noted that scientific advancement could be understood as a *dance of agency* between the scientist's ideas and the material world that it both acts upon and gets acted upon by. Latour described the work of "designing" scientific representations as a dynamic balance between *representational amplification* and *reduction*. The reducing and amplifying qualities of scientific inscriptions make them sites of conceptual innovation, because they use "the distinctive characteristics of the material world to organize phenomena in ways that spoken language cannot—for example, by collecting records of a range of disparate events onto a single visible surface."[57] The objectivity of a scientific representation relies as much on its *antecedent history*—that is, how it got to be, perhaps as an act of coming together of heterogeneous events and representations as Goodwin stated—as well as, Polanyi argued, its *prospective history*, that is, the conjectures and imaginations of what it might become. In becoming scientifically meaningful, *a* representation emerges through the match and mismatch between multiple representations, that in turn are stable for only a historically bounded period.[58]

Todorov[59] argued that there are three primary forms of discourse. *Literal* discourse signifies without evoking anything (no actual text completely achieves this, according to Bakhtin, despite claims by avant-garde novelists of the "New Novel" movement). In *ambiguous* discourse, several meanings of the same utterance are to be taken on exactly the same level. Syntactic, semantic, and pragmatic ambiguity are all possible. In *transparent* discourse, there is no attention given to the literal meaning (for example, in an allegory). What makes code and computer models particularly amenable to science is that they are both ambiguous and transparent. It is therefore no surprise that computational science involves not only learning to use programming languages in contextually (scientifically) relevant ways but also developing new, interdisciplinary ways of talking about and representing the world. Galison termed scientific simulations "trading zones"—a place where divergent ideas and perspectives are brought together, where theory meets experiments.[60] In the same spirit, Nersessian and her group's long-term cognitive ethnographic research on the creation of scientific knowledge in a biomedical engineering lab has poignantly noted that computational work brings together scientists' and engineers' perspectives. In such settings, dissonance between divergent and different representational traditions must be bridged, which results in the invention of novel representational forms that further scientific knowledge.[61]

Finally, it is important to note that the ambiguity and transparency of computational discourse also lend themselves well to design. Simply put, computational design is the predominant form of activity in the K–12 computational science classroom, as students are typically tasked with designing computer models of scientific phenomena. Herbert Simon's call for the centrality of design in technical professions relied on a model that Schön termed "technical rationality." According to this model, problem solving in engineering and scientific disciplines "is the manipulation of available techniques to achieve chosen ends in the face of manageable constraints."[62] Schön's phenomenological account of scientists and engineers at work—given his emphasis on illustrating their *sense experience* as designers—was strikingly different. He argued that technical problem solving is a *radically incomplete* description of what engineers and scientists do. As scientists and engineers address problems that do not fit known categories, their experience can be better understood as a design process that is artistic in nature and involves engaging in reflective conversations with the situation.[63]

Our view of design is grounded in Schön's phenomenological account of design as a reflective conversation with the situation. Like Schön, we adopt the position that when a designer reflects *in* and *on* their practice, the possible objects of reflection are as varied as the kinds of phenomena at hand and the "systems of knowing-in-practice."[64] The latter includes both the disciplinary lenses and norms that the designer brings to the table. The possibilities of reflection arise in the "action-present"[65]—the zone of time in which action can still impact the situation—and these possibilities are varied in nature. Possible sources of reflection-in-action include, for example, tacit norms underlying a judgment, or the strategies and theories implicit in a behavior. The designer may also reflect on the "feeling for a situation"[66] that has led her or him to construct the particular solution, or may evaluate her or his role within the institutional context. Sometimes, reflection-in-action during design also involves negotiating or shifting between different ways of *seeing as*. Schön argues that engaging in these different modes of reflection is essential for coping with divergent situations in practice.

We believe that Schön's "reflective conversations" usually take the form of a combination of ambiguous and transparent discourse, and there is ample evidence that scientists also engage in such discourse. For example, Ochs and Jacoby's observations showed that physicists' early encounters with new problems often begin with attempts to refine rhetorical elements of the potential explanation of the phenomenon. In the world of science, rhetoric is deeply tied to representational work. For example, what at first is treated as a rhetorical problem—for example, how many dots should be drawn on a graph to be displayed in a conference talk—can evolve into a physics problem—for example, what those dots represent in terms of observed or extrapolated physical processes. In these conversations, Ochs and Jacoby observed that while certain matters of rhetoric remain on a less serious or non-canonical plane, attention to rhetoric is often just a first step in a longer deliberation leading to canonical representations and formulations that later become less ambiguous over time and codified as "physics."

To this end, positioning code and coding as heterogeneous language is an instrumental move on our part. Most immediately, it reveals an essential disciplinary heterogeneity, where coding is at once a language *of* science and a language *about* design. In the first image, coding embodies the "doing" and the "concepts" of science. In Schön's terms, it becomes the *design domain* of scientific work as it combines ways of speaking about and representing the relevant phenomenon from multiple perspectives. In the second image, because coding involves dealing with a programming language that is distinct from the commonly used scientific representations such as equations and graphs, it also serves a *metarepresentational* purpose.[67] Thinking and talking about the meaning of code, as well as creating *other* (e.g., material) representations in order to make the code contextually meaningful, can become a way of reflecting about the *nature* of scientific work and design. Both these dimensions become explicit in our analyses presented in the following chapters.

## 2.3 Epilogue: In Defense of Heterogeneity

### 2.3.1 A Critique of Authoritarian Voice

In critiquing monologism and authoritarian voice, Voloshinov / Bakhtin[68] reminded us that:

> History knows no nation whose sacred writings or oral tradition were not to some degree in a language foreign and incomprehensible to the profane. To decipher the mysteries of sacred words was the task meant to be carried out by the priest-philologists. It was on these grounds that ancient philosophy of language was engendered: the Vedic teaching about the word, the Logos of the ancient Greek thinkers, and the biblical philosophy of the word. . . .
> —Bakhtin, 1973, 74.

For Bakhtin, the philosopher and the priest's power comes from their self-declared proximity to the "truth of the word,"[69] a form of authoritarian discourse that is always inaccessible to the rest of society. Bakhtin's dialogical imagination, with a particular emphasis on polyphony and heterogeneity, was fundamentally a challenge to such authoritarian discourse. Critical computing scholars such as Morgan Ames,[70] Safiya Noble,[71] and Lilly Irani[72] have pointed out the dangers of unproblematic adoption of such authoritarian discourse on technology and innovation in terms of exacerbating sociohistorical inequalities. Noble's work unearths how apparently race-neutral algorithms embody and perpetuate racism. Ames reminds us of the dangers of reducing computing education to device-level engagements in the context of challenges with the One Laptop Per Child project. And Irani illustrates the complex interplay of caste, gender, regional identity, and class that underlies practices and experiences of Western and Americo-centric, *colonial*[73] notions of design, technological innovation, and entrepreneurship in the Global South.

Our project here draws inspiration from such critiques of technocentrism and authoritarian discourse on computing. We, however, seek to challenge technocentrism and authoritarian discourse within the microcultures in K–12 STEM classrooms and contexts using an epistemological approach grounded in Bakhtinian heterogeneity. Similar to Bakhtin, the implicit contrast in our work is between an authoritarian image of learning to code and a multivoiced, heteroglossic one. In the former, students and teachers are held captive in their experience of coding as reproduction and recombination of a set of already-known symbolic forms that in turn are understood only by disciplinary experts in computer science. The authoritarian voice here can also be understood as commonly held views of disciplinary authenticity which shape K–12 computing[74] and STEM education.[75] Such reductive views of authenticity primarily rely on a narrow set of experiences and perspectives of disciplinary expertise (e.g., reductive definitions of computational thinking, see Section 1.3) which teachers and students must conform to. In our case, this also reifies a technocentric image in which coding is positioned as device-level engagements, in which the heterogeneity of experience is lost or silenced. For researchers, adhering to such views imply that technological productions (forms of computer code) need to be considered as the primary form of data from which they must infer students' experience. In contrast, we have argued that focusing on perspectives, alterity, and transparency of the experience of code as language—rather than simply looking at code and computational structures and representations themselves—may offer a fundamentally richer imagination of coding. This image centers the experiences and lives of the learners and teachers, and does not frame their experiences as imprints of disciplinary canons. This, in essence, is the shift from computational artifacts to computational utterances.

### 2.3.2 A Turn Toward Critical Phenomenology

The turn toward utterances is a turn toward experience, and thus, decidedly phenomenological. As Merleau-Ponty argued, a phenomenological agenda relies on *radical reflection* through which we must "rupture our familiarity" with the *sphere of givenness*[76] and the familiar must reveal itself in new ways.[77] Things that once spoke, over time, become buried in our cultural worlds: they may lose their revealing capability over time, hiding essential elements of experience from our view. Our cautionary notes about the unproblematic adoption of "computational abstractions" and "computational thinking" as lenses to look at coding stems from similar concerns. They can subsume and hide the complexity of the experience of coding. It is this form of monologic discourse which Bakhtin argued is an extension of authority. It is important to guard against such discourse, as it might render homogeneous the heterogeneity of our possible experiences of code.

Furthermore, we have argued that our pathway to a *critical* phenomenology of coding is premised on the inherent alterity, ambiguity, and transparency of computing as discourse (for example, see 2.2.2.2). It is an essential reminder that experience is not universal. Especially in the context of technoscience, accounts of experience typically privilege the few with ready access to the inner sanctums of technoscience. Paying attention to heterogeneity in the form of perspectives, alterity, ambiguity, and transparency, can help us question accounts of technocentrism, unsilence critical conversations, and center voices from the margins. This is evident in our work, as we bring to light the following: the complex work of negotiating perspectives even during the earliest steps of modeling, a phenomenon that is usually ignored in technocentric accounts of agent-based modeling (chapter 3); thinking about, interacting with, and designing for an authentic audience—an account that challenges device-centered images of computing (chapter 4); and talking about possible experiences of racialization and inequality in the context of reasoning about simulations of segregation (chapter 5). At the same time, *what* gets voiced through these experiences of alterity and the question of *who* is voicing are also of profound importance. How do teachers with no prior coding experience—whose voices are often ignored in our accounts of science, STEM and computing education—adopt and appropriate coding as an integral part of their science classrooms (chapter 6)? How can racialized students who have been historically left out of disciplinarily rich opportunities for coding find themselves as *authors* of code in STEM classrooms (chapter 7)?

Alongside Bakhtin's arguments, we have also drawn parallels to the scholarship on science studies that present an analogous image of science in practice. Scientific objects—physical or symbolic—are imagined as heterogeneous discourse, their heterogeneity rooted both in their ontogenesis and their yet-unfolded becomings.[78] They are as much carriers of historically grounded meanings as they are tools to imagine new meanings. As Rheinberger noted using Derrida's words, scientific objects represent "a differential typology of forms of iteration"[79] that still seeks elaboration. The objectivity of scientific objects, in this perspective, takes on a *différant* form, because their meanings are both emergent and postponed, unfolding themselves in new (but connected) ways in future discourse.[80] Polanyi further points out that différance is actually rooted in our sense experiences of scientific objects, in that we *trust* scientific objects to have "the independence and power to manifest itself in yet unthought ways in the future."[81] The chapters that follow reveal such *différant* images of code and coding in K–12 STEM contexts, challenging notions of disciplinary homogeneity and inviting us to open the doors of our perception to the myriad becomings of code as heterogeneous utterances in K–12 STEM contexts.

## Notes

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25. Rosebery et al., "The coat traps all your body heat," 2010, 325–326.

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