EPISTEMIC REKEYING: EPISTEMIC TENSIONS ACROSS DISCIPLINES AS OPPORTUNITIES FOR ARTISTIC RESPONSE

Corey Brady
Southern Methodist University
corey.brady@smu.edu

Lauren Vogelstein
New York University
lev226@nyu.edu

There are strong motivations to implement integrated STEAM activities that engage with key ideas in mathematics. In integrating mathematics with other STEM disciplines, however, epistemic tensions can emerge. Rather than attempting to suppress, avoid, or adjudicate these tensions, we propose a strategy of "epistemic rekeying," in which epistemic tensions are offered as provocations for students to create playful and artistic responses. This approach takes epistemic tensions seriously and makes them accessible to young learners. We give the rationale for this approach and describe settings where students' creativity suggested its potential to us.

Keywords: Integrated STEM / STEAM, Mathematical Representations, Computational Thinking, Classroom Discourse.

STEM and STEAM integration (Takeuchi et al, 2020) signal possibilities for integrative learning experiences involving multiple disciplines. A number of different arguments have been made for STEAM integration, including the increasingly trans-disciplinary nature of scientific research (National Science Foundation, 2019; Nersessian, 2017) or the observation that problems in the world of work are seldom confined to a single school subject area (Lesh, Hamilton, & Kaput, 2007). One can also argue that integrative STEAM activities may enhance students' interest and increase the relevance of STEM subjects (Lehrer & Schauble, 2020).

Epistemic Tensions

In spite of their promise, integrative STEAM activities that involve representational tools and practices can encounter emergent tensions between the distinct epistemic frames that characterize different disciplinary ways of knowing. Such tensions can be seen as problematic, creating hidden challenges for both teachers and students that may distract from instructional objectives (Lehrer & Schauble, 2020). Moreover, epistemic tensions are *essential* to and *inherent* in interdisciplinary work: the literature on professional boundary crossing (Akkerman & Bakker, 2011; Osbeck & Nersessian, 2017) has studied a variety of different personal and institutional responses to such tensions, revealing the rich array of ways of life that can arise at disciplinary intersections. Thus, mathematics educators cannot simply "design around" these tensions: doing so may even risk falsifying the participants' experience of interdisciplinarity.

To address this dilemma, we propose an approach to integrative STEAM activities, in which the epistemic tensions in representations, practices, and ways of knowing of two disciplines are foregrounded in playful, shared embodiment activities experienced by classroom groups of students. Students are then invited to engage aesthetically with the ideas that these epistemic tensions have evoked for them. Aesthetically keying (Goffman, 1974) these activities can enable learners to make creative use of such interdisciplinary tensions and explore them through expressive action. We argue that this form of epistemic rekeying offers an approach to interdisciplinarity that neither trivializes tensions between disciplines nor presents these tensions as inaccessible to younger learners.

We investigate a research and practice problem core to STEAM integration: *How can we engage students with agency, in the face of epistemic tensions in disciplinary ways of knowing?* We illustrate the emergence of the epistemic rekeying approach in work within the Computation and Mathematics Play Spaces (CAMPS) project, which engaged middle-school (Grades 5-8) students in formal and informal settings, to integrate mathematics and computational thinking in the context of artistic expression.

We show how rekeying activities toward artistic expression enabled students to approach epistemic tensions in ways that shifted *away* from frames highlighting “correctness” (and adjudication between contrasting disciplinary perspectives) to frames highlighting “generativity” that could playfully engage with tensions, exploring the expressive potential of representations. Our “epistemic re-keying” approach is still in formation; in addition to analyzing activities, we thus also share conjecture maps (Sandoval, 2014) to show how epistemic rekeying may be a general approach to constructing integrative STEAM activities.

Theoretical Framework: Frames, Framing, and Rekeying

The framing of a situation or interaction reflects participants’ negotiated determination of “what is going on here” (Goffman, 1974). Faced with a barrage of information that is overwhelming and often conflicting, humans have to make snap decisions about what “kind” of situation they are in, in order to determine what is relevant, what the rules are, and how they should act. It is remarkable, then, that framing can often be done implicitly and without uncertainty rising to conscious experience, especially since framing is a matter of shared agreement and coordination (Goffman, 1974). Episodes within integrative STEAM activities are often (implicitly or explicitly) framed as under the aegis of one discipline or another.

In unfamiliar environments, however, questions of framing can come to occupy the foreground (DeLiema, Enyedy, & Danish, 2019). Novel settings make it more likely than usual for multiple candidate framings to emerge, as participants look for contextual clues about the tools, participation structures, language, and interactions that are appropriate. Such settings can offer different frames for different people (Hand, Penuel, & Gutierrez, 2012), or make it ambiguous both to participants and to outside observers what is actually going on (Wisittanawat & Gresalfi, 2021). In integrative STEAM activities, epistemic tensions can provoke frame indeterminacy, when the interpretive lenses of two disciplines yield different meanings for a representation or action. Frame indeterminacy can be experienced as a crisis or breakdown, but situations designed to provoke frame indeterminacy can also bring together different interpretations of shared experience, thus offering powerful learning opportunities.

In addition to shifting from one frame to another, social groups can modify frames in ways that Goffman (1974) describes as keying, and re-keying. The paradigmatic example of rekeying is play: following Bateson’s (1956; 1972) reflections on animals’ play, Goffman describes how in play, a primary activity can be transformed. For instance, when dogs play at fighting, biting, growling, and many other recognizable actions remain, but because they are wrapped in the signal “this is play” they lose their original meanings and take on new significance. In our approach to integrative STEAM activities, we look for opportunities to invite students to rekey epistemic tensions as provocations for playful and aesthetic response.

Disciplinary Context: Mathematics and Computer Science in the NetLogo Environment

NetLogo (Wilensky, 1999) is an agent-based modeling environment widely used in classrooms and educational research, to model complex systems in the natural and social worlds (Wilensky & Rand, 2015). The NetLogo world consists of two main types of computational entities: “patches,” which form a Cartesian grid in the world, and “turtles,” which can move about at a layer above the patches. In the CAMPS project, we supported students in learning to program, and using mathematical representations and logic to create artistic computational performances that employed both of these NetLogo agent types (Brady et al, 2020; Brady 2021).

Epistemic Tension: Continuous and Discrete Representations of Space

A key emergent issue in our designs was the representation of space as continuous (mathematics) or as discrete (computer science). In a continuous representation (e.g. Cartesian plane), space is infinitely divisible in each dimension; in contrast, in a discrete representation (e.g. images composed of pixels), there is a minimum resolution that can be distinguished. Familiar mathematical formalizations of lived space depend upon the representation of space as continuous. Fundamental concepts such as the density of the rational numbers in the reals and the theory of limits and convergence of sequences of numbers and functions rely upon a view of space as infinitely subdividable and continuous, as opposed to ‘chunky’ and discrete. In contrast, computational representations typically use finite precision, which defines a granularity to space. Indeed, it is arguable that discretization is fundamental to and inevitable in all digital representations.

Learners encounter shocks to their intuition when confronted with consequences of both continuous and discrete representations, and so it is *not* clear that one of these two is more “natural” to humans than the other. For instance, even after accepting a proposition that matter is discrete (e.g., that an atomic component such as a quark may be indivisible), people have trouble with the idea that the space in which this matter exists is discrete (e.g., that these smallest particles cannot move smoothly but must change their location by ‘jumping’ the minimal spatial grain-size.) Moreover, what about discrete *time*? On the other hand, some propositions rooted in a continuous perspective can be received as equally counter-intuitive. For instance, a continuous view of number holds that in selecting a number between 0 and 1 at random, the probability of selecting any particular number, say, ½, is zero. A discrete view rescues us from this apparent paradox – with a “grain size” or “resolution” of 1/1000 (“three decimal places”), the probability of selection for each number in [0,1) is 1/1000. Since there are 1000 such numbers, the probabilities add as learners expect.

All coordinates in the NetLogo environment have limited precision and are hence discrete, thus the patch grid presents learners a salient version of “chunky,” discrete space. In this paper we share the analysis of how entailments of the highly-discrete patch space became problematic for a group of students engaged in a shared-embodiment activity in which they played the role of the patch grid in their class (cf. Vogelstein & Brady, 2019; Brady 2021). Epistemic tensions about the representation of space also appeared in activities where students embodied and programed turtles, though space limitations permit only a brief sketch of one such activity.

Methods

The CAMPS project has produced three summer camps integrating math, computation, and art, co-designed and facilitated with middle-school mathematics teachers from a large urban district in the southeastern United States. Our first camp used graphic arts to foster connections between mathematics and agent-based programming. This “Image Camp” highlighted NetLogo patches, treating patches as pixels and used collective embodied and computational activities that encouraged students to explore how the group of patches could produce computational compositions and visual effects. In Year 2, we added a second camp that focused on performative movement expressed in choreography and code. This “Action Camp” highlighted how large numbers of NetLogo turtles can create dramatic effects as they move and change in concert. In addition to the camps, some partner teachers arranged to bring adaptations of camp activities to their students during the school year.

In this paper, we analyze data from a "Code Friday" session in the 7th grade mathematics classroom (N=34 students) of one of the lead teachers, Ms. S. Ms. S was a veteran teacher with over 25 years of teaching experience. The school where she taught served a student population that was diverse both economically and racially.

The mathematics class in which Ms. S ran "Code Friday" was an honors class; students in the class were consented to participate in a year-long study of these sessions. Multiple data sources feed our analysis here: video from a mobile camera and computer screen recordings from a subset of consenting students comprise the primary corpus. Focal episodes were identified based on field notes and initial viewing of the video record, highlighting students constructing and making sense of the patch grid's representation of points and lines. We used interaction analysis (Jordan & Henderson, 1995; Hall & Stevens, 2015) methods, repeatedly viewing video; attending to students' and teachers' epistemic framing; and considering dialog, intonation, gesture, and embodied expressivity to characterize clashes and shifts in epistemic frames. We continually discussed and compared our interpretations to iteratively refine them.

Findings

The Code Friday session that is the focus of this analysis began with a shared-embodiment activity, called the *Stadium Cards activity.* This was an activity Ms. S had taught the previous summer (Vogelstein & Brady, 2019) and that she re-organized for her 7th grade class. In it, a subset of the class collectively embodied a small 2x5 patch grid (see Figure 1, below), while the rest of the class watched and commented on the patch-actors' work. Ms. S acted as the NetLogo *Observer* (the Observer has a 'global' view and can issue commands to *all* patches, to individual patches, or to any subset of patches). In this role, she used NetLogo syntax to ask patches to change their "patch color" (called "pcolor" in NetLogo syntax). Many of the prompts of the activity engaged with the idea of the patches' varying *state* (a computer-science concept referring to the current value of its variables), and with the NetLogo representation of color as a number between 0 and 140, with a "wrapping" rule, so that the color 141 is the same as the color 1 (a mathematics concept pertaining to *modular arithmetic*). The Stadium Cards activities were challenging for learners, who worked to make sense of the "epistemic games" (Shaffer, 2005) involved in the world of NetLogo agents and their syntax, *decoding* it (Vogelstein & Brady, 2019) in the way that a traveler might decipher a foreign language (cf. Papert, 1980).

Disagreements among the students were resolved by encouraging students to articulate their thinking, and then learning the rules of these epistemic games. For example, in response to:

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"ask patches, set pcolor pcolor plus three"
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One student interpreted the command as setting the pcolor to the *value* of the signed number "+3." The mathematical indeterminacy and lexical novelty of the computer-science variable assignment (`set x x + 3`), permitted this interpretation, and Ms. S recognized the student's logic before facilitating a discussion toward the NetLogo meaning, captured by a student who demonstrated "`pcolor + 3`" by advancing the color on the color-card ring three times. Here, the design of the color-card ring manifested modular arithmetic and supported the "NetLogo logic" of modular arithmetic and color wrapping. Each patch-actor could consult the representational tool of the color-card ring, resolving the tension between arithmetic results (adding 3 to the number of their current color), and the "wrapping" rule.

The final Stadium Cards challenge of the day was designed to introduce NetLogo's system of coordinates as a means to refer to patches by their location in the grid. The 2x5 grid was augmented with white index cards, intended to identify the coordinates along each dimension (0 and 1 along the horizontal axis closest to the camera and crossing the frame; 0 to 4 along the vertical axis on the left, extending from the camera toward Ms. S.) In contrast to the color-cards, as we will see below, the representational infrastructure for coordinates was distributed spatially and therefore needed to be consulted or "read" from a particular location and orientation.

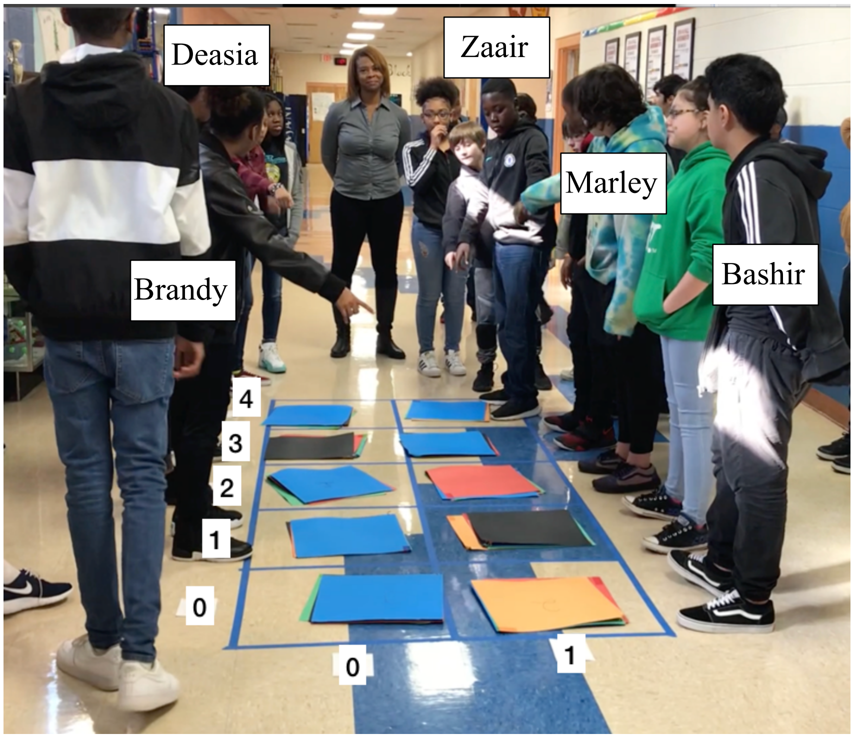

Figure 1. The Stadium Cards activity. Each student standing around the 2x5 patch grid was responsible for their patch. They controlled the color of their patch by manipulating the bound ring of colored paper and replacing the stack in the grid-space. Coordinate labels were written on index cards. The image is annotated to make them more legible.

After telling the group that the patches had coordinates, Ms. S issued the command:

`"ask patch one four, set pcolor orange"`

The class intensely debated *which* patch would have the coordinates 1 4. (The four models of the grid that appeared in students' discourse are shown in Figure 2.) There were two sources of disagreement. One arose from the challenge students experienced in shifting their view of the patch grid to locate the origin and construct the positive coordinate axis directions. Students tended to reason from a perspective in which the patch to the lower-left of the grid *from their standing point* was the origin. Figure 2a shows one student's viewpoint that follows this line of reasoning (as well as reversing the order of x- and y- coordinates, presumably to allow the coordinate pair (1, 4) to appear on the grid). Challenges related to standing point ***do*** connect with representational feedback, practices and conventions associated with the Cartesian plane, but since they do not deal with disciplinary tensions, they are peripheral to our analytic focus.

The second challenge arose from the ambiguity of the placement and nature of the origin and of the 0-coordinate in each dimension. We had placed index cards at the centers of the patch axis intervals, in an attempt to indicate the patch-coordinates. These patch coordinates defined a discrete description of the plane: all patch-coordinates are integers, and thus NetLogo's patch origin is the patch whose x- and y-coordinates are both zero (see Figure 2b). In contrast, many participating students' reasoning drew upon a ***mathematical*** representational convention that was cued by the Stadium Card grid. To support students in knowing where to put their ringed stacks of patch colors, we created a grid of taped lines. This "background" structure offered support for a view of the Cartesian plane (used in *mathematical* practices with representational tools such as graph paper) in which *gridlines* represent the location of exact-integer coordinates. In particular, under this interpretation, the lower-most and left-most tape-lines would represent the *x*- and *y*-axes respectively, and the origin would be a point at ***the bottom-left corner*** of the patch mentioned above (see Figure 2c). Thus, the coordinate 1 4 would be *between* patches – in the middle of the grid and at the point touched by the "top" four patches (see Figure 2c).

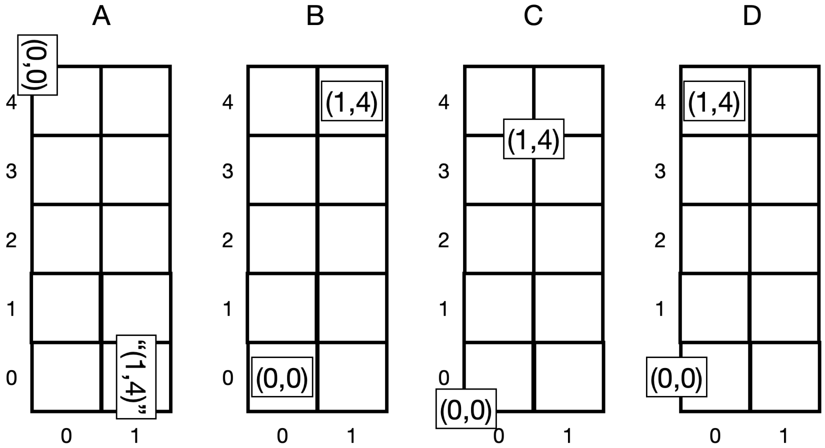

Figure 2. Inferred assignments of the origin based on students' answers to where patch 1 4 would be.

A fourth and final, hybridized perspective, which combined the two conventions, emerged in the argumentation of one vocal student, Brandy. Brandy's conclusion was that Deasia was the actor for the patch 1 4. This was initially puzzling to her peers, perhaps since it appeared to combine a discrete view of the grid in the y-direction with a continuous view in the x-direction. Articulating her different interpretation, Brandy said:

Brandy: Guess who's on y [pointing to Deasia] and guess who's number 4? [pointing again]

This way of presenting her thought reveals a key feature of shared embodiment in the activity. Our description above of the cues for the two perspectives neglected to consider the positioning of physical bodies of students who were animating the patches. Students stood off the grid, either to the left of patches with x-coordinate 0, or to the right of patches with x-coordinate 1. No patch-actors stood above or below the grid. That meant the actors' bodies indexed the y-coordinates but not the x-coordinates. Thus, for a student attending to the actors' bodies, the "origin actor" was standing at the location marked in Figure 2d. If one combines an actor-centered perspective of locations on the y-axis, with a measurement-movement perspective of the x-axis in this way, it is entirely comprehensible that the coordinate 1 4 would be reached by the actor "on y" and "who's number 4" taking one step in the positive-x direction. This conception would not address how to issue commands to students on the right-hand side of the grid, but neither Brandy nor Deasia was in that position.

Deasia responded immediately to Brandy, pointing to the "0" label on the x-axis at the other end of the grid and saying "But that says zero." Next, Marley (a patch-actor on the right-hand side of the grid) asked Brandy, "Are you saying that you do y first?" Marley's comment was initially puzzling. However, she may have been trying to understand Brandy's method, from the perspective of her own patch, or have been responding to Brandy's implied method of getting to 1 4 (namely, that the actor at y=4 should take one step in the positive x direction). Further, because "doing y first" would violate a maxim of reading coordinates ("x is first," which had been voiced by several students) she could be using the phrase to question the validity of Brandy's method.

Consensus emerged at the end of the debate that Zaair was in fact the actor that NetLogo would designate as patch 1 4, and that he should change his color. As a way of giving voice to a still-unresolved tension she sensed in the students' thinking, the second author offered a perspective highlighting the discreteness of the patch coordinate system: "in NetLogo…zero has a *thickness* to it; everything has a *width* to it…."

On returning to the classroom and the NetLogo environment, students were given several minutes of free coding time to experiment with the ideas and syntax they had just encountered. They also had their "NetLogo phrasebook," which many students explored. Bashir took the opportunity to explore the idea of the thickness of computational lines. He started by returning to a phenomenon that the class had found strange in earlier work – namely that the y = x line was pixelated when drawn with patches. At the corners between pixels, this "line" had no thickness, while in the middle it was quite thick. Bashir typed in the Command Center:

```
ask patches [if pxcor = pycor [set pcolor 94]]
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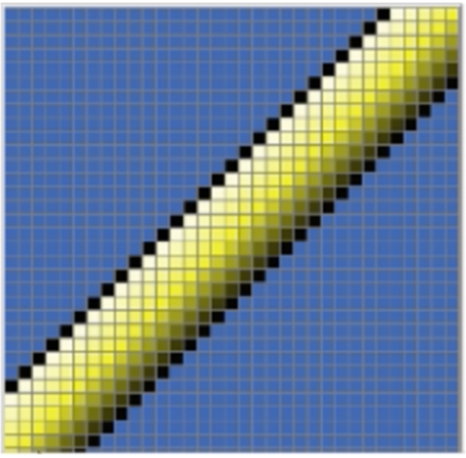
After trying several numbers as colors, he decided on yellow (45), and explored what nearby numbers looked like (e.g., 45-1). He rapidly typed the sequence of commands in Figure 3, using the Command Center feature to recall the last command issued, and then editing it:



```
ask patches [if pxcor = pycor - 1 [set pcolor 45 - 1] ]
ask patches [if pxcor = pycor [set pcolor 45] ]
ask patches [if pxcor = pycor - 2 [set pcolor 45 - 2] ]
ask patches [if pxcor = pycor - 3 [set pcolor 45 - 3] ]
ask patches [if pxcor = pycor - 4 [set pcolor 45 - 4] ]
ask patches [if pxcor = pycor - 5 [set pcolor 45 - 5] ]
ask patches [if pxcor = pycor + 5 [set pcolor 45 + 5] ]
ask patches [if pxcor = pycor + 4 [set pcolor 45 + 4] ]
ask patches [if pxcor = pycor + 3 [set pcolor 45 + 3] ]
ask patches [if pxcor = pycor + 2 [set pcolor 45 + 2] ]
ask patches [if pxcor = pycor + 1 [set pcolor 45 + 1] ]
```

Figure 3. Bashir's iterative construction of a "cool" 3D line.

In this work, Bashir built on prior coding activities (which explored how small changes to syntax could make big changes to the effect of the code), and on his experiences in the Stadium Cards activity (assigning numbers to colors and to locations, and noting that patches whose coordinates differed by one were right next to each other). He used these novel and unfamiliar findings to explore how he could achieve a visual effect related to the class's problem about line pixelation. Changing color and position in a coordinated, stepwise fashion, he created a three-dimensional effect that he showed off to his table neighbors and the class as a whole as “cool.”

Discovering Epistemic Rekeying

Bashir’s artistic use of the ideas from prior activities was an unexpected innovation for us, and if his response had been unique, we might not have attended to it in our ongoing design iterations. However, several students in the class played artistically with the ideas from this activity, and in other activities, we saw similar tendencies. For an example also exploring the discrete-continuous epistemic tension, several students in the Action Camp (now embodying *turtles*), became fascinated with rules that involved a precise x-coordinate value (x=0). A turtle’s coordinates can take on decimal values, so that when it moves across the screen, it may never trigger an “if xcor = 0” rule. They invented choreographic rules that relied on the condition (xcor = 0) being one turtles would reliably achieve. Turtles would execute one behavior if they met the condition, “xcor < 0,” another if they met “xcor > 0,” and the *combined* behavior if they met “xcor = 0.” Implementing these rules brought both computational and aesthetic rewards.

Conjecture Mapping

As we have encountered the inventive responses of children when they are presented with epistemic tensions, we have come to see the potential in rekeying these tensions as provocations for artistic production. We propose that this may be a generative design element for creating and facilitating integrative STEAM activities. We capture this idea in the following conjecture map:

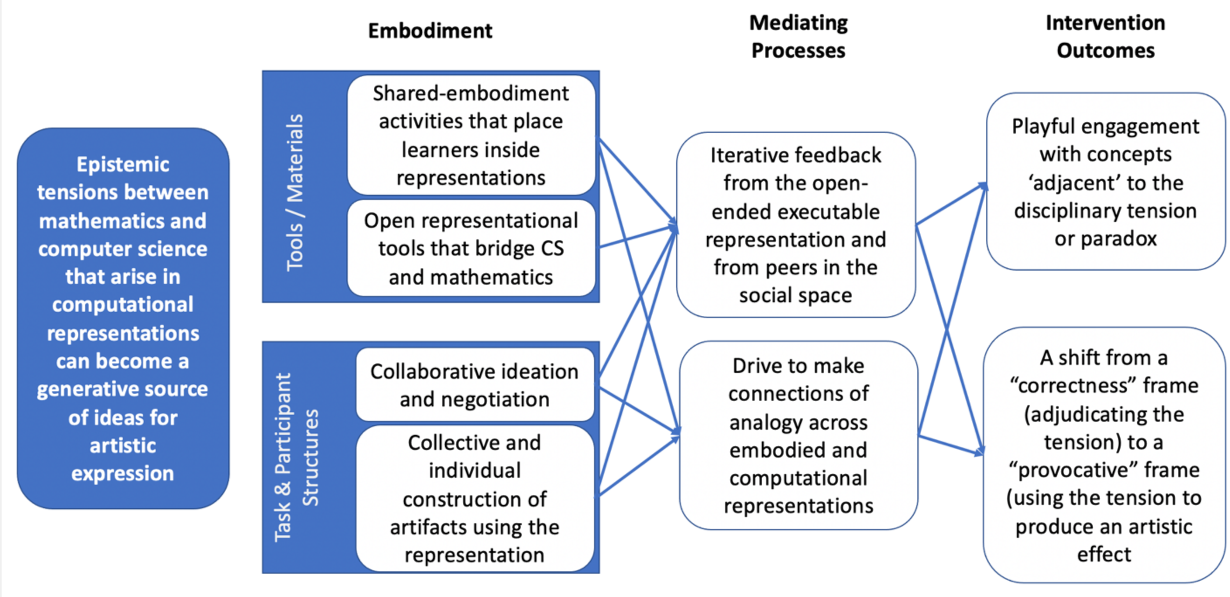


Figure 4. Conjecture map for epistemic rekeying in integrative STEAM activity sequences.

Discussion and Conclusions

In this paper we have described our route to formulating a design element for integrative STEAM activities, which we call epistemic rekeying. We identified the essential problem that it solves, in addressing epistemic tensions between disciplinary practices of representation, and we described an instance of an activity sequence, beginning with a shared embodiment activity, followed by independent creative work, in which students playfully engaged with the epistemic tension as a provocation for artistic creation. Finally, we shared our current conjecture map.

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