CHAPTER 8

Reconfiguring STEAM through Material Enactments of Mathematics and Arts: A Diffractive Reading of Young People's Intradisciplinary Math-Artworks

Pamela Burnard, Pallawi Sinha, Carine Steyn, Kristóf Fenyvesi, Christopher Brownell, Olivier Werner and Zsolt Lavicza

Abstract

The current movement to integrate arts within STEAM education is relevant not only for responding to complex societal and economic problems of the twenty-first century, but in that it carries its own sets of processes, questions and paradigmatic shifts that decentre dominant discourses in education. This chapter argues onto-epistemologically that arts uniquely engender *a "mutuality" of disciplines* constituted in the intra-actively entangled production of new knowledges through knowing and doing enactments within STEAM (re)configurings. It argues this is a form of critical intradisciplinarity. This chapter, which draws on an exceptionally significant data set, reports a novel analysis of a sample of drawings called "math-artworks". These were created by South African young people in Grades 8–12 following a series of mathematics-art-experiential workshops. Theoretically framed by posthuman feminist new materialism, the chapter diffractively reads three of these drawings. It asks what matters in mathematical-art drawings by using Karen Barad's concept of diffraction as a methodological practice for reading these drawings as data. The chapter uses diffractive reading to evaluate what it is that "math-artworks" advance, as encountered in the material enactments of South African young people. It also asks whether these configurings of intradisciplinary knowledge making generate new pedagogic repertoires. It argues accordingly that STEAM is a form of critical intradisciplinarity that is capable of activating future-making education.

Keywords

Barad – diffractive analysis – future-making education – intradisciplinarity – new materialism – new pedagogic repertoires – posthuman – (re)configuring STEAM – relational knowing

 | DOI: 10.1163/9789004421585_012

1 Introduction

The concept of STEAM education is fairly new and lacks a clear-cut definition (Colucci-Gray et al., 2017). STEAM education intends to promote and develop the integration of the arts into the subjects science, technology, engineering and mathematics. In this chapter we argue that the arts do *not* need to be integrated within STEM subjects. On the contrary, the disciplinary formations or (re)configurings offered by the arts in STEAM education create enabling spaces for a *mutuality of disciplines* which have the potential to introduce students to future-making education.

In this chapter, we rethink the concepts of interdisciplinarity and multidisciplinarity in the context of the territorialisation of knowledge (Ingold, 2018: 75). *Multidisciplinarity* becomes reduced to friction, as disciplines are either used side by side (multidisciplinary) or adopted in parallel or sequentially from one domain to another. *Interdisciplinarity* denotes building a bridge *between* disciplines, where disciplinary identities remain preserved (Collin, 2009). Interdisciplinarity is perceived as a process whereby learning occurs from a disciplinary-specific basis for the purpose of solving a common problem. *Transdisciplinarity*, on the other hand, seeks to preserve various disciplinary perspectives and confront them with each other. Transdisciplinarity does however acknowledge the "different realities" and ways of thinking in different disciplines, but at the same time it challenges the differing parties or disciplines to readjust their perspectives. Transdisciplinary learning differs from interdisciplinary practices in that it occurs when participants share a conceptual framework to draw together disciplinary-specific theories or concepts. Research tells us that interdisciplinary and transdisciplinary learning moves learners beyond knowledge acquisition to knowledge collaboration and knowledge production (Beane, 2011). The separate, subject-based organisation of curriculum as it currently exists in many schools is a longstanding legacy of theories of psychology and mental discipline which, although discredited by the turn of the twentieth century, still influence curriculum theories.

The configurings of mathematics and art encounters in STEAM are never simply "mirroring", "interfering" or "meeting" from their disciplinary distances. In fact, within the individual and mutual *spacetimematterings* (Barad, 2003) of mathematics and art there is an *entanglement*, signifying the ontological inseparability of "agentially intra-acting components" (2003: 815). We draw heavily on Karen Barad, a Professor of Feminist Studies, Philosophy, and History of Consciousness at the University of California, Santa Cruz. Why? Barad reinterprets theoretical thinking from both the social and natural sciences to define a new theory of knowing, which rejects both positivist and purely discursive

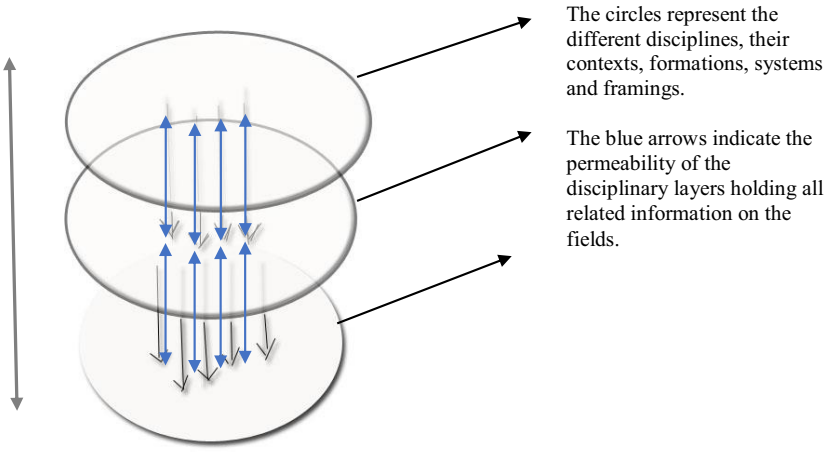


FIGURE 8.1 Reconfiguring disciplines

theories of knowledge. In connecting discursive and material aspects of reality, Barad's (2007) "onto-epistemology" also resonates deeply with STEAM (re) configuring because of how made material objects (in this case the mathematical-art drawings-as-text task) invoke a new set of pedagogic strategies for future-making education. Barad explains that "[t]o be entangled is not simply to be intertwined with another, as in the joining of separate entities, but to lack an independent, self-contained existence ... individuals emerge through and as part of their entangled *intra-relating*" (2007: ix, emphasis added). For Barad, *intra-activity* is that which builds an understanding of the inseparability of the "observed object" and the "agencies of observation", the observer and the observed, and our intra-action with other bodies (both human and non-human) produces subjectivities and performative *enactments*. Emerging anew from the *agentially intra-acting* formations, phenomena and components (human and non-human) – in this case, of the two disciplines, mathematics and art – we are able to (re)formulate and re-turn the math-art materiality into a dialogic "appreciation of the intertwining of ethics, knowing, and being" (Barad, 2007: 185). This is a math-art connection making and doing, or what Barad refers to as ethico-onto-epistemology. Such cutting together-apart of *agentially intra-acting binaries* – as with math–art, mind–body, social–science, material–discursive, discourse–affect, textual–visual, theory–practice, historical–political and geographical–socioeconomic – reveals how 'boundaries are there but never determinate or permanent, always changing and becoming' (Murris, 2018, p. 20). This allows us to see differences relationally, to diffract and differentiate, and re-turn our "gaze" on math-art. In response, intradisciplinarity *neither begets dominance of any one discipline* (as observed in interdisciplinarity)

nor does it maintain the distance between individual disciplines (reflective of multidisciplinarity), or demand readjustments (as with transdisciplinarity). Instead, through our study we observe that intradisciplinarity (as shown in Figure 8.1) is constituted of permeable layers of differing disciplines, including their conceptual frameworks, practices or norms. It relies on the relational and dynamic entanglements, intersections and differences offered by the disciplines, allowing for emerging assemblages and plateaus that generate common ground – or disagreements. Their material-discursive agencies (re)new formations and phenomena, shaping a new space for (re)connected thinking and practice. Intradisciplinarity actualises and uncovers the un/foldings between subject disciplines.

In this chapter we ask how art(s) come to matter in the relational knowing enabled by reconfiguring of STEAM. How does art(s) in STEAM set up relational knowing, that is, putting knowledge(s) and the mutuality of disciplines to work intra-actively?

What follows is a methodological rationale for our analysis of drawings-as-text. Our concept of "drawings-as-text" necessitates a rethinking of drawings as a material enactment of mathematics and art. The drawing is seen as a text for interrogating, which is different from how drawings are "voiced" and viewed in secondary school art classes. We are asking what young people can tell us – as explored in justifications for the use of visual methods (Thomson, 2008; Murris & Thompson, 2016) – and also what they add as an onto-epistemic reconfiguration of voice, through material enactments with mathematics and art drawings-as-text. For Barad, it is impossible to separate or isolate practices of knowing, doing and being because "they are mutually implicated" (2007: 185). The physical world is not at a distance, on the other side of a line, but all "knowledge-making practices, including the use and testing of scientific concepts, are *material enactments* that contribute to, and are a part of the phenomenon we describe" (Barad, 2007: 32, emphasis added). From Barad we are alerted to how the use of images opens up powerful ways of knowing, being and doing that do more than merely represent but rather emphasise the new that is produced through the "drawings-as-text".

2 Analysing Material Enactments: Materialising Diffractive Methods

This chapter draws on an earlier international project which focused on making math–art connections (Fenyvesi et al., 2019). The aim was to improve student outcomes in mathematics, particularly in rural areas of South Africa. Growing out of the experiential workshops generated by Kristof Fenyvesi, one of the

authors of the study,[1] and organised by Nelson Mandela University's Govan Mbeki Mathematics Development Centre (GMMDC) in 2018, as part of their STEAM education development program, a math-art drawing competition was launched. It was free and open to all secondary school learners from Eastern Cape Province.[2] The original study, initially reported at a conference in 2018 by Fenyvesi et al. generated over five hundred math-artworks accompanied by individualised statements of expression.[3] These were contributed by children, youth and teachers from 37 schools of varying socioeconomic status across the Eastern Cape Province, the poorest of South Africa's nine provinces. The math-art competition was designed in response to South African learners' low mathematics performance, as demonstrated in national and international studies (Spaull, 2019). Arts was introduced to stimulate thinking about and expressing mathematics creatively, particularly as creativity has risen from tenth to third place in the ranking of top skills listed by the World Economic Forum (2016). Learners from Grades 8 to 12 were encouraged to participate, with the objective to understand learners' "inward" and "outward" performance (between the mathematics and arts, for future making).

What is particular to the South African context? There appears to be a sustained divide between historically "white" and "black" schools based on socioeconomic disparities, language differences and the impact of former educational policies. While historically "white" public education includes more affluent schools with better teacher training and a focus on motivating learners, the historically "black" schools are economically disadvantaged, suffering from diminished efficacy, low teacher expectations and motivation, a resistance to change, and lack of appropriate infrastructure (see Wolhuter, 2014; Spaull, 2019). Further, mathematics education in South Africa continues to rely on rigid, traditional pedagogies concerned only with lower cognitive levels, despite researchers arguing for more learner-centred and creative approaches to teaching mathematics (Wolhuter, 2014). In contrast, Tsanwani et al. (2014) found that a positive perception (of oneself, mathematics and their teachers) appears to influence disadvantaged learners to persist in mathematics. Fenyvesi et al. (2019) argue that studies of embodied mathematics (wherein maths is performed, whether through visual art, dance or music) have shown positive results, particularly for children with disabilities and learning difficulties. Out of the total of 500 drawing submissions, 113 were selected by the competition organisers to be studied by this chapter's authors, who then created their own criteria for analysis of 87 submissions, then narrowed them down to 20 final math-artworks to be re-read and (re)configured.

The study drew on the concept of diffraction (see Haraway, 1997; Barad, 2007) as a methodological practice of reading "insights through one another"

and making diffractive or different, entangled understandings that led to "new cuts".[4] Doing so made it important also to examine the contemporary formal education system in South Africa which, having emerged from post-Apartheid politics only two decades ago, remains highly unequal. For the purposes of this chapter, the authors have not re-visited older readings but rather diffractively read anew a sample of three of the twenty artworks.

Our research team included seven mathematics and art experts with a particular interest in education, who have contributed to STEM, STEAM, mathematics, and the study of arts and creativities education and research. Hailing from diverse countries (Finland, USA, South Africa, India and the UK), they have extensive experience both in the practice of and researching STEAM education.

Our first task involved coding for mathematical and art knowledge, skills, practices, and meanings from the initial selection of 200 drawings and statements of intent offered from the total of 500 drawn by the South African youth and children.[5] Of these, 20 math-artworks and their accompanying statements that were most frequently selected by the team formed the basis of our study. This prompted the team to develop an entangled, intra-acting, disciplinary criteria for selecting these pieces of work. We decided upon math-artworks that offered: a "deep" and differentiated understanding of mathematics and art; greater abstraction and creativity in "doing" math-art literacies, concepts and knowledges; a richer, more embodied and relational understanding of math–art connections; and an investment beyond the realms of the curriculum. It led us to investigate and emphasise the social, cognitive and psychological aspects of mathematics and arts.[6]

Finally, this dataset of math-artworks was then narrowed down to three drawings that enabled us to make multiple-level and ongoing connections between the conceptual and the experiential, the cultural and the historical, the concrete and the abstract, the visual–textual, and the rhythmic and the unstructured, facilitating a "deep" diffraction of the matter of matter. It opened up a transitional space, a field of emergence where terms that make up binaries (self–other, subject–object, math–art, inside–outside, ontologies–realities) intersect, cross over and participate in a shared realm of relational knowing.

3 Doing Diffractive Analysis

Building on Barad's notion of "entanglement", which expresses the idea that reality and language, nature and culture, matter and meaning are inextricably entwined (Barad, 2007: 3), we engaged in an extensive and diffractive reading

of the individual artists' "knowing" and "doing" (performativity, affect and disciplinary differentiations). In particular, our reading elaborated how specific nuances generated by the students', as well as researchers', intra-actions and embodiment of mathematics and arts access differing knowledge formations and build understanding of the materiality of the two disciplines within their specific *spacetimematterings*. While multiple, enmeshed and shared insights drew this qualitative analysis away from habitual, normative readings, diffraction also enabled an understanding of unpredictable patterns producing different knowledges generated by differing disciplines. In time, these became active sites for: excavating the connections emerging from math-artwork inquiries located across differences (geographical, economic, political, sociocultural); understanding how inequalities influence learner perceptions and experiences of mathematics; and garnering transdisciplinary insights to develop a discursive math-art method. Emerging from team discussions and the "new cuts" offered by the two disciplines, the following sections acknowledge that diffractive analyses produce more questions than answers (often revealing knowledges only in analysis, after the coding of qualitative inquiry).

The practice of diffraction has made us ask further questions in our rereading of the math-artworks accompanied by their statements of intent, which were generative and iterative. What is the painting comprised of? What elements, symbols or artefacts complete it? Who is the artist/youth/learner? What does their art say? How far does it entangle with their written statement? What is interesting to the artist in making the math–art connections? What are the specific indications of the iterative (re)configurations (of the material, discursive, social, political, geographical, temporal or conditional) and elements (line, colour, symbols, formulae, metaphor, layout, concept) within the provided materials? We then started to brainstorm "What else is going on here?" and explored the artworks collaboratively. This urged us to move away from a humanist analysis or an anthropocentric gaze (that is, to not only focus on humans, their knowledges, emotions or intentions) to entangle with the matter (content, idea) and its materiality (making, materials used). We asked: What material or matter is interesting to the artist? Do the materials help construct particular emotions, concepts, ideas or knowledges? Does it matter that certain colours, shapes or figures are featured? What do the materials or matter permit or prevent? What do they invite, exclude or regulate? What about the matter and materiality of mathematics and arts as disciplines? What do their materialities and discourses include, emphasise or neglect? Do we assume that the mathematics and the arts knowledges are separate entities, and what difference would it make for our analysis if considered one? What did this math-art activity of drawing, making connection and reflecting do? How did the act

of drawing open up "new" spaces or cuts that provoked young people's imagination, to think differently, to test ideas, make affected connections or create intra-active spaces?

In terms of the social or political conditions of these young people's everyday lives, of maths and art, spaces and time, we asked: What does it mean to engage with the discursive materiality of the mathematics and art, particularly for South African youth? Are there emerging binaries in their entanglement with math-art? If so, which of these are assumed, neglected or open to entanglement? Where, when and how is the young people's agency expressed? What is the role of knowledge and who decides upon it? And whose knowledge matters?

In this following section, we show how reading diffractively presents spaces for building a relational, entangled yet differentiated understanding of the math-artwork phenomenon, and argue for intradisciplinarity, a new cut emerging from the study.

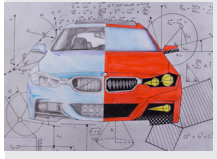
4 Diffractively Reading Math-Artworks (Drawings-as-Text)

What follows is our own enactment of diffractive analysis. To do so, we chose three of the most frequently selected artworks for diffractive analysis (see Table 8.1 for an introduction to the three students). In engaging with the material, social, political and geographical conditions of math-artworks, we have read and (re)read the images, re-turning their gaze from individual disciplinary perspectives to the *dynamism of forces* (Barad, 2007: 141) in which all constitutive "things" work mutually and inseparably. We are drawn away from habitual, normative readings. These drawings-as-texts become active sites for *excavating* the connections emerging from math-art inquiries located across differences (geographical, economic, political and sociocultural).

4.1 *Doing Diffractive Readings of Drawing-as-Text 1:* The Stressed Vitruvian Man *by Euclid*

> Artist's statement: This artwork implies how Mathematics is involved in our daily lives. It gives the impression of *how intact Maths is* and [how] *effective Maths is.* Upon the decision of choosing this specific image, I made it clear that Mathematics could have a *positive or negative impacts*. A few examples of *how we experience Math daily* are measurements of our clothing; which is why in my artwork you will see the right side has measurements that is in centimetres which is used to measure clothes. *Clothes* require accurate calculations together with the fact that

TABLE 8.1 Additional details concerning student, school, and competition

Artwork title & student name	**Student details (Grade, age, gender, subjects taken, SES)**	**School type (size, gendered, location – city/rural) & math and art teachers**	**Competition entry details**
'Mechanism' by Jabulani 	Grade 12, 17 years, male Race: coloured SES: lower average income group Learner was in grade 12 last year which is the final year of school. School attendance: good Learner stays close to the school: ~1.5 km Jabulani chose Mathematics and Physical Science for FET (grade 10–12). Jabulani's results for maths and science for grade 11 and 12 were low.	Quintile 3 (non-fee-paying), public secondary school, co-ed, urban Public state school in city residential suburb. The residential suburb was allocated to the coloured community during apartheid but is now a multicultural residential area. The school is a secondary school for grade 8–12 learners. There are ~1043 learners. Maths teachers are qualified to teach Maths.Art is not taught as a subject for grade 10–12. There is no Art Club at the school. Thus, learners with an interest in art do this on their own at home.	This drawing was Jabulani's first and only entry to the competition. The drawing shows his very keen interest in engineering, geometry and design.

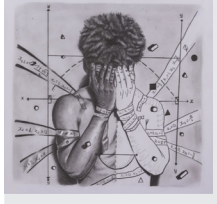
(*cont.*)

TABLE 8.1 Additional details concerning student, school, and competition (*cont.*)

Artwork title & student name	**Student details (Grade, age, gender, subjects taken, SES)**	**School type (size, gendered, location – city/rural) & math and art teachers**	**Competition entry details**
'Soul Number' by Annika 	Learner was in grade 10 last year and currently in grade 11. She is part of a Maths and Science project on Saturdays. Her attendance there is excellent and her marks in the project classes are higher than the marks that she gets at school. Annika chose Mathematics and Physical Science for FET (grade 10–12). Her school results for maths and science for grade 10 and 11 were average but tends to fluctuate a lot	Quintile 4 (not full fee paying), public school secondary school, only girls, urban The school is on catholic church property. The school is in a residential area in the city of Port Elizabeth. The residential suburb was allocated to the coloured community during apartheid but is now a multicultural residential area. The school is the last Catholic Secondary School for multi-racial pupils in the Northern Areas of Port Elizabeth. All these areas are economically deprived, and unemployment is very high. The school is a secondary school for grade 8–12 learners.	This drawing was Annika's second attempt on entering the competition. Her first attempt was only a drawing of a girl but when questioned by a teacher on the link to maths she changed the drawing to include the number lines.

(*cont.*)

TABLE 8.1 Additional details concerning student, school, and competition (*cont.*)

Artwork title & student name	**Student details (Grade, age, gender, subjects taken, SES)**	**School type (size, gendered, location – city/rural) & math and art teachers**	**Competition entry details**
		There are ~563 girls enrolled. Maths teachers are qualified to teach Maths. Art is not taught as a subject for grade 10–12. There is no Art Club at the school. Thus, learners with an interest in art do this on their own at home.	
***'The Vitruvian Man'* by Euclid** 	Grade 11, 16 years, male Race: Black SES: Low income group (single parent)	Private school, co-ed, urban. The school is a private school that was established in 2012 as a result of the need for a caring educational facility that could provide education in an urban environment.	This drawing is a self-portrait. Euclid entered the competition because he wanted to get recognition for his artwork and not due to an interest in mathematics.

(*cont.*)

TABLE 8.1 Additional details concerning student, school, and competition (*cont.*)

Artwork title & student name	**Student details (Grade, age, gender, subjects taken, SES)**	**School type (size, gendered, location – city/rural) & math and art teachers**	**Competition entry details**
	Learner was in grade 11 last year and currently in grade 12. Distance of the learner's home to school is ~7 km and popular mode of travel is by mini-bus taxi. Euclid results in maths were not good enough to continue to grade 12 with maths and he was moved to the mathematical literacy class. However, his other subjects results are good to average. One of Jabulani's other artworks was selected to put on the front page of the school newspaper. He sells his artworks for an income.	A partnership with churches and the community resulted in an educational model where everyone could be accommodated. The school is situated in the business district of the city in a building that originally housed shops and offices. The school has learners from grade R–12 (thus combined junior and secondary school). There are ~900 learners in the school. Maths teachers are qualified to teach Maths. Art is not taught as a subject for gr 10–12. There is an Art Club at the school and learners are encouraged to take part.	When asked about his inspiration, he replied: "I was inspired from Leonardo's drawings, his old notebook. I entered the competition because I was fascinated with art and tried to excel more in my art. I tried to get exposure for my art".

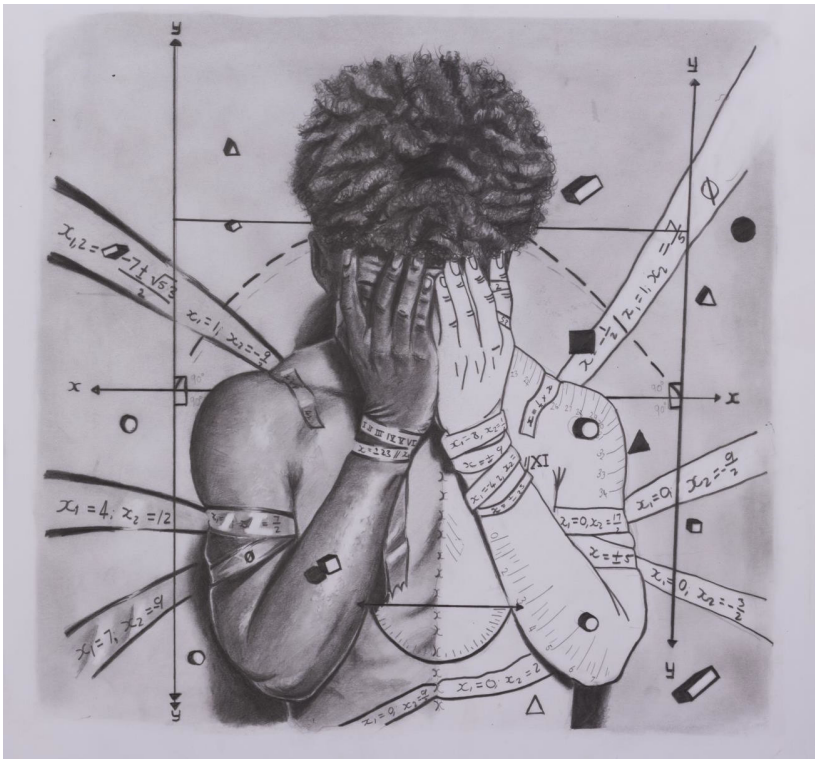


FIGURE 8.2 *The stressed Vitruvian man* by Euclid,[7] a male, aged 16 years, in grade 11 at a private school that facilitates learners from less privileged backgrounds and thus has a socioeconomically varied environment

our *bodies* are asymmetrical; which you see the left side does not look like the right side. We need our measurements to make sure we get the right fittings. My artwork illustrates the simplicity which is how the effect of maths has been ignored and neglected. My illustration also *shows the reality of Mathematics*, that even though it is interesting and effective, Mathematics could prove to be stressing especially for teenagers who have other interests. *The artwork has the main figure who is stressed.* I've indicated that his head is slightly bowed to show the negative impact. The *hands* which cover the *face* are an indication of frustration. This has brought about the reality which I didn't intend to hide. The answers to the equations represent that there is always a solution. This is a form of encouragement to the mathematical society. I placed the equations on different places to show that there are different ways to get the answer. On the same note, I've shown that if done frequently Math could cause a *negative toil* inside every part of the brain. The two sides have different

> shading as indication to the *positive* (simple art, no shading) and *negative* (complicated side with shading) influence of the subject on a person. I call it "The Stressed Vitruvian Man"; would be the modern version of Da Vinci's artwork. I admire the artist a lot and I feel we might have the *same ideals* on art. The lines on the background are from the Vitruvian Man with his *arms* open and *legs* spread out.

This young man's drawing focuses on himself, his hair, his hands and his body, and shares how he thinks of and experiences the consequences of mathematics education. He has drawn a self-portrait in which he cannot separate the learner from what is learned as a way of being (and continuous becoming) in the world. This seems dependent, in this time and space, on giving expression to a form of knowing and his experience of the subject. For this young man, it seems that learning is understood in response to an essentialist view on development and learning where he is judged (and seen here to be judging himself) in relation to his own mathematical development and progression, and status (or lack of) as a mathematician. The monotonality reflects different shades of black with strong cultural references. The bi-tonal hands are productive of difference that comes to matter in the cultural and historical elements and cultural associations of anxiety, emotions and bodily reactions which connect and take action with/in his body. He communicates stress, solemnness and seriousness. Does this produce a view that normalises young people in accordance with dominant views on mathematical development? As researchers and observers of this drawing, we are invited into the world of the mathematician and artist, as part of his world.

The artist seems not to separate the mathematics from the art. The patterns show evidence of superimpositions – the new patterns created are the effect of difference and mark where learning has occurred. The learner is not separated from *what* is learned. He seems to be thinking with and through the relational nature of mathematical concepts, expression and form. While the mathematical concepts featured here include algebraic expressions of solutions to equations, the ideas of analytic geometry and its reliance upon an origin point at the intersection of orthogonal axes, and the mutuality in methods of solving systems of equations intra-acts with two-dimensional space projected from a three-dimensional space, evoking visually stunning and mathematical complexity. We also see that the human body is the seat of mathematical knowledge and through Euclid's art we see him as a knowledge producer. The intra-action between mathematics and arts is mutual and relational: things "are" because they are in relation to and influencing each other. We connect with a young man and his experience of mathematics, which is inscribed on his body.

What else is going on here? Our next thought is that the learning of mathematics is practices of knowing *in* being mathematical, which is something experienced through the body. Karen Barad argues that you cannot isolate knowing from being, since they are mutually implicated. We see this clearly in this drawing, which is putting to work a mediated image of Leonardo DaVinci's *Vitruvian man*. We see a close material-discursive relationship drawn and displaying what appears to be more than a subject–object divide. As Karen Barad states, "knowing is a matter of *part of the world making itself intelligible to another part*" (2007: 185, emphasis added). We connect with a young man. We connect with the maths equations inscribed on his body, from his body, through his body. We see the maths doing something to him, stressing him out, closing him down. All of these are overlapping forces. They are entangled with/in his body, clothes, gestures and emotions in the production of his realities as he becomes *The stressed Vitruvian man*. With his head positioned/held/balanced/almost hidden between his hands, with just a tiny peephole small enough to see through, his divided body and divided encounter with mathematics materialises, in the careful pencil shading. We see how learning is produced through participation in the "math-artwork" operating on the learner and the learner operating on the maths through complex intra-actions of multiple *material-discursive* (bodily, material and discursive) productions (Barad, 2003: 8).

An epistemological device is attributed to the artist; it is assumed that he cannot separate mathematics from its embodied meaning. The maths is experienced. The maths is performed. The maths is inscribed on his body, which is divided by shadings and by ruler markings that measure his left/white arm. All within this space is given agency because of the intra-action between what is left out and put in through the plight of knowing the limits of his mathematical knowing, as a normalising, self-managing discursive practice of knowledge acquisition. Is this a result of the structure and struggle of the rational mind, the lived experience of mathematics? Why has he drawn himself? How can a self-portrait express mathematical knowings? What if he is genetically preprogrammed to unfold in predetermined directions? What if he is not a blank slate, though, but rather is reflecting an educational space and place which is seen to be "filled" with knowledge. He seems to be asking: Why is learning mathematics so hard? Barad (2007: 91) states very clearly that the point is not that knowing has material consequences, but "practices of knowing are specific material engagements that participate in (re)configuring the world".

The experience of *doing* mathematics, learning (*knowing*) mathematics and expressing mathematics seems to involve differences; with different effects conveyed by nuanced shades of grey, black, slate, charcoal. At best, it would

seem that doing mathematics involves interacting realities and ruptures. Or is there a continuum drawn across a maths–art binary? The association with mathematics, inscribed and unfolding across the artist's body, intra-acts with creative lateral connections that are drawn to show an association between the art and the human exceptionalism of polymath Leonardo da Vinci and his *Vitruvian man*, which shows the proportions of the human body. He is making clear that *The Vitruvian man* is based on *de Architectura*, a building guide written by Roman architect and engineer Vitruvius. It matters to him that, as a master of the arts, sciences and everything in between, Leonardo da Vinci is a "Renaissance man". Intended to explore the idea of proportion, the piece is part work of art and part mathematical diagram, conveying the old master's belief that everything connects to everything else. There is a great deal of detail concerning and connecting the proportions of the body and the regulation of the body through the spatial-material organisation of the body. There is a great deal of matter mattering as floating mathematical shapes, floating in space and still intra-acting with the body, in front, beside and behind, returning as reminders or cues to ask: "What is mathematics?" "When is mathematics?" "Why does mathematics matter?" The shadings matter a lot. The shadings shed light on the relational nature of difference; thinking with and through difference as a matter of "mathness" and "artness" in the world.

The drawing seems to be working with barriers to enjoying mathematics while making new patterns of thinking and doing. There is a demonstration of a lot of skill and technique. There is also a binary shading which attends to the relational nature of mathematics and art. Here Euclid seems to speak of the asymmetry of our bodies. Maybe this is deconstructive, working with barriers, rather than a reductive view of teaching and learning. A polarising of learners' emotional wellbeing and the troubling of intellectual needs are the effect of mathematics. Is this inconsequential? What do we hear, in the commentary, about the learner questioning and experiencing feelings, ideas, shifts in consciousness and an imagining of different realities? Could he be trying to suspend disbelief and work in fictional contexts using a range of mathematics devices, dilemmas and demands? Could this be an expression of deep understandings about the need to enact and embody mathematics learning and about his making the familiar strange inside the art "work"?

How is art offering a power-producing intra-action between mathematics and being a young man growing up in South Africa? What matters? This does not look like a comfort zone. He appears not to be inviting or sustaining a desire to engage with (dis)comfort. What else counts then? Is there a challenge here to traditional conceptions of why education matters? In order to see the world through another's eyes (could it be Leonardo di Vinci's?) we must

enter into their world and understand how it looks. Perhaps this is what it is to be "wide awake" to activate our mathematical imaginations, to really see "the abandoned ones, the homeless ones, the broken windows, the redesigned museum, what is absent, what is realized" (Greene, 1978, p. 45)? Is he trying to re-imagine mathematics as an alternative reality? Is he envisaging what might be possible (social imagination) and hopefully bringing about a change in himself as he becomes aware of how the mathematics and art work, connect, overlap, interfere and change in themselves in intra-action and together create an interference; what we call "learning"? Can he see that embedding the arts in learning experiences can play a pivotal role in enhancing students' imaginative and creative capacities while improving and fostering such understanding? Are these multiple intra-acting agents that are connections to spacetime mattering? What else matters and becomes possible future realities because of this? The critical issues here are that there are no inherent and clear borders between matter and discourse and no clear borders between being and knowing, being and doing. This makes knowing just as much a matter of the body and material as it is a matter of understanding and thinking through these subjects of mathematics and art, which cannot be separated but merge intra-actively. Euclid is thinking with and through mathematics and art and making new patterns of thought (superimpositions), deconstructing power-producing binaries (mind–body, mathematics–art) and showing how these disciplines overlap and change in themselves in intra-action, being concerned with what they *do* and how they are connected and co-constituted.

4.2 *Doing Diffractive Readings of Drawing-as-Text 2:* Soul number *by Annika*

Artist's statement: In my drawing I have chosen to use numberlines as numbers can go on till *infinity* and our *hair* grows continuously, *non-stop*, this is a comparison between the two. The numberlines as *hair* is representing the *roots of our lives* as we cannot go one day without counting or using numbers to represent or solve anything. I have drawn a *little demonic girl* and as you can see the numbers close to her *head* are small numbers, but as they go on, the numbers increase continuously and there is *no end*. This represents the *knowledge we obtain in our everyday lives*, subjects and Maths. I've used *black and white because those* colours are *drab* and my interest in Maths before was *boring*. The little bit of red shows my *slow interest* in Maths. To me Maths is like a *demon slowly stealing my soul*, like I'm *becoming addicted* to it and *starting to enjoy* it.

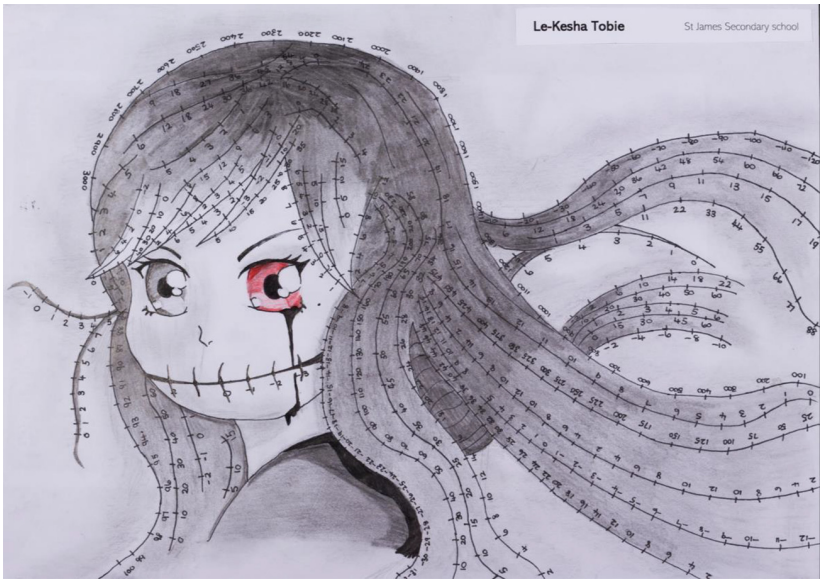


FIGURE 8.3 *Soul number* by Annika, a female, aged 15 years, in Grade 10 at a fee-paying public school where the school community is from low to average socioeconomic background

In "cutting together-apart"[8] (Barad, 2014; Chappell et al., 2019; Murris & Bozalek, 2019) Annika's math-artwork, the immediate question to arise is: Is this articulated as a self-portrait? Is she taking what she finds inventive and trying to work carefully with the details of patterns of thinking in their materiality of mathematics and art as predicated on her own view of herself? Even if not, working reiteratively with the math-artwork and the statement offered, the image appears to be internalised, giving us access to an inner world. Consider the "othering" of the demonic girl before the math-artist's growing self-relation to maths, as it multiplies and is embodied ("like a demon slowly stealing my soul", "becoming addicted"). Making connections (between the material, descriptive, conditional and conceptual dimensions) in this young woman's math-art realities involves "re-working the spacetimemattering of thought patterns and not turning away from or leaving behind" (Murris & Bozalek, 2019: 1512).

Annika offers insights into her worldly spaces of school–home, everyday–extraordinary, material–conceptual, production and performative understandings of practices of knowing. Most markedly, the image appears to have been excavated from the wider materiality of Japanese manga or anime, at once crossing over boundaries of spacetime, culture, physical location and economics. This is what Barad refers to as the move toward "performative alternatives",

enabling a "*performative* understanding of discursive practices" beyond representationalism (2003: 802, emphasis in original).[9] The artist communicates the complex and sophisticated mathematical concept of infinity and number sequencing with dexterity, revealing a remarkable metaphoric quality and abstraction of ideas and of self (pre- and post-math-art self, manga self, South African self, student self, math-artist self). The number-lines in the form of the flowing hair create visual texture, rhythm and nuanced compositional definitions. Does this intimate that knowledge is "unending", hinted also by hair drawn so that it seems to continue past the page? There is an abundance of symbolism (monotone image with focus on one eye, hair related to "roots of our lives" and the concept of infinity) and visual codes (unending number-lines, stitched lips, the red eye) in the image. We begin by asking why red? Is it indicative of a growing passion, a self-demonisation or evocative of both these imageries? The featured use of grey related to the drab, contrasting with one red eye, introduces a dramatic and embodied affect. Is this a symbolic self-reference to the ongoing nature of the young woman's developing relationship with mathematics, previously considered "boring"? Annika's monotone shading, and use of black and white spaces, further transform the math-artwork into a visually and emotionally meaningful entanglement embodied by the artist.

The young woman offers differing sites for reading the descriptive matter diffractively. To start with, the title itself, *Soul number*, has multiple connotations (soul music emerging from black subcultures, maths in music, internalisation of maths) for the "new" math-artist's "being-becoming". The head itself and the encompassing hair is framed by numbers. Does this relate to the artist's reconfiguration of maths as inescapable, to maths as the "roots of our lives"? Within the descriptive material-discursive matter of the statement, we see the unfolding of the young woman's mind regarding the nature of mathematics and her personal encounter (and thereon entanglement) with it. Reflecting on the ubiquitous quality of mathematics, she considers how our lives "cannot go one day without … using numbers to represent or solve anything". But she acknowledges that she has employed monotones as a metaphor for the "drab" in mathematics, with the red eye wide awake in this artful expression. At first, such description and depiction of mathematics seems sinister, as she indicates the reason for the colouring of the eye is to signify her slowly growing interest, possibly to the point of addiction. Her embodiment of knowing offers insights into her pathways of intradisciplinary formations.

Locating the conditional or mutual co-existence of material-discursive matter within this math-artwork led to the young woman's declaration that our lives "cannot go one day without" maths. Is this observation conditional,

founded on the hierarchies of STEM subjects adapted by nation-states for their own devices? Mathematics is further related to "knowledge we obtain in our everyday lives"; why is art not? Does the South African formal education system or families relegate art to a secondary status? Or is it in fact a more personal reflection, emerging from the enactments of math-art pathways? The (re)readings of her thought patterns, as offered by the image, always drew our adult or gendered "gaze" to the sewn lips, quietened out of the image and the text. Does this imply the debilitating effect of mathematics teaching and learning on her, silencing her voice, cognitive abilities or personal attributes? Is it symbolic of her plight as a young woman in South Africa or as a fan of manga, anime or gaming? Further, the young woman's emotive self-critique (via the demonic subject) begs the question: Is the self-demonisation a reflection of her incapacity for mathematics or others' expectation of being maths capable? It guides acknowledgement also of the material realities of "'being-of-the-world', not 'being-in-the-world'" (Barad, 2007: 160), reducible neither to one or the multiple. As Barad writes:

> [W]hat is at issue and at stake is a matter of the nature of reality, not merely a matter of human experience or human understandings of the world. Beyond the issue of how the body is positioned and situated in the world is the matter of how bodies are constituted along with the world, or rather as "part" of the world (i.e., "being-of-the-world", not "being-in-the-world"). (Barad, 2007: 160)

This math-artwork is abundant in (re)configurations of conceptual matter emerging from the encounters with and meetings of the two disciplines. This is seen in Annika's characterisation of numbers as hair roots and hair as infinity, a smiling mouth but with the lips sewn together, and the red eye with what appears to be ink/tears flowing down the face. These create spaces for "evocative dissonance" as they appear to suggest an overall happy, curious and creative demeanour inflicted by repressed anxieties or suppressed anger felt by the social and intellectual distances created by maths. Reflecting on her affective responses to mathematics, this "math-artful" expression seems highly charged. Annika's embodiment of math-art and its materialisation in everyday life is visible in the mathematical concepts employed, primarily hinting at infinity via the "non-stop" number sequencing. Metaphorically represented, infinity is seen in Annika's usage of sequences embedded in the hair of the figure. The realism of transforming complex mathematical concepts into an aesthetically expressive and intrinsically evocative "math-art" drawing-as-text reveals perspicuity and strong conceptual/technical knowledge. The image foregrounds

such "ongoing being-becoming" (Barad, 2014: 181–182). We see this in the subtle distinctions between the colours red and grey that have differing and similar connotations in different countries, systems and social traditions; the symbolic use of mathematical symbols and techniques; and the cross-cultural travel of Japanese materials such as manga and anime books or films, which have found appreciation in the Eastern Cape region of South Africa.

4.3 *Doing Diffractive Readings of Drawing-as-Text 3:* Mechanis *by Jabulani*

> Artist's statement: This drawing shows us the relation between *engineering and geometry* and how they are related to engineers and designers. Cars are not only *built* and *sold*. They are carefully thought through and *designed* machines which come in all shapes and sizes. During the period of *designing a car*, everything must be *measured* and *shaped* precisely. If one part is not measured or shaped to specifications, one of the major components which is *aerodynamics* will be *negatively affected*. This then influences the fuel consumption/*economy*, due to drag and air friction. Geometry and EGD are subjects which prepare learners to pursue a *career* in this field. At my school *we do not have the opportunity* to nurture our *skill* in the *arts, design or mechanics/engineering*. A *lack of resources and interest* shown by *our government deprives learners* like myself an opportunity to get a head start to get the necessary foundation that would prepare one for such a *career*.

Jabulani's composition of his math-artwork directs attention to the forward placement of the car in relation to the mathematical expressions set in the background, as they fade out in perspective. Both are articulated with and through the other. Both are affected by and affect each other. Both are entangled. What is striking about the image are its clean lines, the conceptualisation and precision of the drawing, the artist's technical aptitude in realising his vision. It brings together "discipline-specific cognition"[10] and materiality translated via implicit binaries – a mutual co-existence of a whole (maths–arts, concept–practice, economics–education, local–global, dominant–disadvantaged). Hence, the car, as a subject of the math-artwork itself, seems to have been decisively divided into two parts. We notice the colour (blue-grey on the left, and red and yellow on the right) and form (realistic versus graphic). Is this an expression of the mutual co-existence of mathematics and arts? Or is this devised to contrast the technical with the artistic, which cannot be separated in processes of knowing and doing (Barad, 2007)?

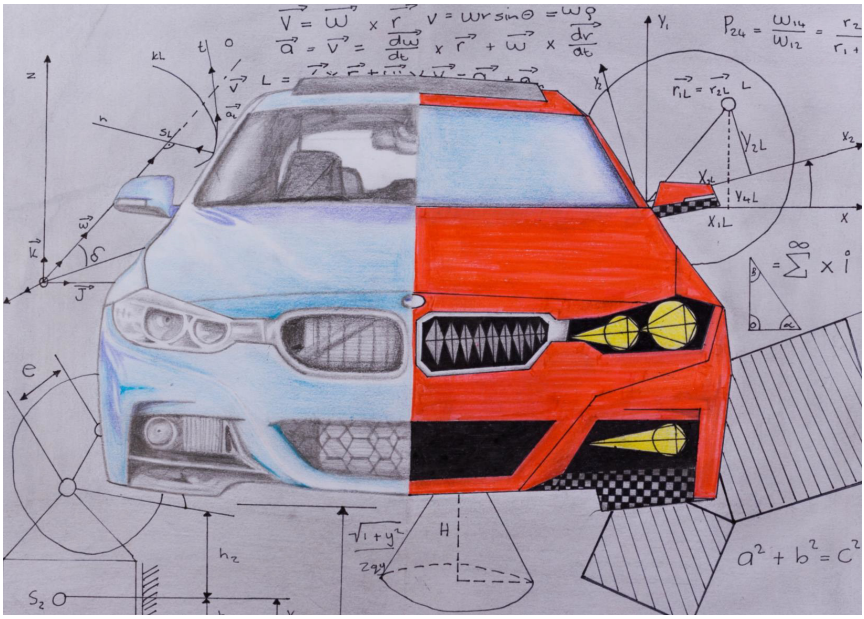


FIGURE 8.4 *Mechanis* by Jabulani, a male, age 17 years, in Grade 12 at a non-fee-paying public school, from a low socioeconomic background

Analysing the artwork diffractively at once urges "going deep" and considering "what else?" Why did the young man choose automobile design to express his mathematical-artful concepts in the first place? Where does this young man's proclivity for the automobile industry emerge from, even as he reflects that his school does not provide "the opportunity to nurture our skill in the arts, design or mechanics/engineering"? Does it have any references to the popular subculture related to motor car or dirt racing and design? In asking what else is going on, the car's framing by mathematical formulae and symbols raises the question of their function. How do they relate to the car, if at all? Have they been employed creatively, allowing the observer's imagination to take over? Or are these in fact accurate mathematical formulae and calculations used in car making, employed here to heighten the idea of precision? Is the young man being allegorical in making available the view of the car interiors seen through the left side of the windscreen, and not the right, or is it merely the prying and controlling adult "gaze" interpreting a play of math-art identities? If metaphoric, in this instance does it signify the young man's embodiment or the specific enactments of the two distinct disciplines?

In *excavating* the young man's relationship with the *matter that matters*, the artist's *materiality* of math-art and agency of math-art matter shows no boundaries between aesthetic skills (for example, use of symbols and metaphor or

layout and design) and technical knowledge (say, drawing three-dimensionally, application of perspective). These intra-active forces mutually perform the specificities of the two disciplines but also the learner's specific personal experience ("we do not have the opportunity") and economic conditions (lack of resources and interest). Jabulani's math-artwork makes explicit connections to the conditional dimensions of the young man's lived math-art experience. This is set up in relation to his analysis of the *political conditions* of education (government depriving learners) and socioeconomic status (of the school or home) and future employability as he reflects on the lack of "necessary foundations". He says: "A lack of resources and interest shown by our government deprives learners like myself an opportunity to get a head start … that would prepare one for such a career". Such self-expression/reference/interest offered by Jabulani's artwork, and statement, provides discursive material for dialectic entanglements. This is demonstrated in his understanding of the interrelationship between mathematics, art and economics as significant to designing vehicles but also in reflections about how these may shape his future career path. So, does his intention to show "the relation between engineering and geometry and … engineers and designers" reveal an instinctive humanising of the discipline?

Aesthetically, the *conditional dimensions* invite questions with regard to the cultural connotations of using the colours blue (left side of the car) and red (right parts). Red could be symbolic of excitement at completion, or indicative of passion for one's dream. Blue is positively associated with cool temperatures, soothing to the eye, but also depression (thus "having the blues"). Were such references considered? If so, were these intentional or innate? The colours may also reflect the learner's (dis)agency with reference to mathematics as a human practice or the warmth and cold of the disciplines as lived experience, whilst also making the embodiment of math-art explicit. Studying what matter matters here, through a material-discursive dialectic lens, necessitated moving beyond traditional textual literacy to include colours, symbols and implicit codes. Consider why the young man chose to include symbols such as sigma and infinity (not directly related to car making) alongside what appear to be formulae for aerodynamics, acceleration, pressure and light reflection). Why are the mathematical symbols dispersed in the background, foregrounded only by the finished product, the car? Does it seek to build understanding of the dispersed nature of knowledge and information to be garnered or is it in fact emphasising them as building blocks for necessary outcomes, finished or unfinished? His understanding of the wider conditions (say, his school's or his own economic status or politics that limit disciplinary conditions) suggests an agentic self or, in Barad's terms, an "agentic realism" on Jabulani's part, through which he makes new "cuts" that add to the existing math-art assemblages.

These new "agential cuts" allow for the *conceptual* and the non-representational, expressed beyond the boundaries of the two disciplines, and economics and geopolitical conditions. The conceptual connections made available by Jabulani's math-artwork present evident intersections of the artist's *knowingdoingbeing*. He opines, "Cars are not only built and sold. They are carefully thought through", thus attending to the relational nature of math-art values and economics. We see this also in multiple voicings of the word "mechanism", which references: (a) the "mechanics" of making, whether a math-artwork or a physical car, (b) the political "mechanisms" (governance, hierarchies of disciplines and knowledge itself) that reproduce social inequities, and (c) the "machinations" of connecting and implementing the conceptual with the conditional, actions to ideas, and self within its wider contexts. Artistically, inquiry about the distinct differences presented between the left of the car (realistic but appearing to be a blueprint, outlined in blue-grey tones), and the right (graphic and seemingly completed illustration, in red), draws attention to the artist's abstraction, metaphoric quality and interest in representation.

This math-artwork offers multilevel connections. This young man has made a carving of the material realities of his intradisciplinary pathways to experiencing mathematics as art and art as mathematics. He seems to be seeking out the relational aspects of math–art intra-actions, relating them to economy, governance, careers and lack of resources.

5 Resisting Easy Answers: Troubling the Practice of Knowing

At the beginning of this chapter we argued that there is a critical need to deepen understanding of how arts knowing in STEAM configurings comes to matter. We have introduced new evidence on how the materials used to make art and to think discursively with mathematics offer new understandings of how mathematics and art can intra-act. We have seen in these three cases different (re)configurations of STEAM; where being, knowing and doing enactments of mathematics and art not only engender a "mutuality" of disciplines but also produce new knowledge that is capable of activating a future-making education.

In this chapter, we featured research that reports a novel analysis of a sample of drawings-as-text which we have called "math-artworks" that were created by Grade 8–12 South African students following a series of mathematics-art-experiential workshops. We conducted diffractive readings using feminist new

materialism, where a sample of three drawings-as-text generated insights and new questions, opening up other possible meanings/matterings concerning the connectivity between mathematics and art and what possibilities become available when young people experiment and explore the material and discursive dimensions of mathematics and art simultaneously.

In trying to make visible the intra-active play between mathematics and art, the practices of knowing enact what we know (knowing), who we are (being) and how we action this (doing). In secondary school, teachers recognise that they are asking young people to make huge leaps to conceive of themselves as "doing" and "acting" but also "being" mathematicians and artists. This practice of knowing invokes/provokes/invites paying close, responsive and responseable (enabling response) attention to a new set of pedagogic strategies for future-making education. Troubling the hegemonic notions of what constitutes mathematics education/learning and art education/learning, framed by feminist new materialist perspectives, opens up the possibilities that subject disciplines can be more engaging, relevant and less alienating. STEAM ca (re) configure and activate a future-making education by attending to differences in all their detail, creatively repatterning STEAM as specific material engagements and practices of knowing. Tracing these entanglements is key.

We ask what does such a math-artwork drawing-as-text task and the diffractive analysis of these math-artworks invoke in terms of configuring pedagogic strategies for future-making education? We experimented with Karen Barad's (2007) concept of diffraction as a methodological practice of reading, which offered much more than simply an alternative form of analysis or an alternative to teacher reflection. Rather, we found that diffractive analysis became a metaphor which depicts "insights through one another", which expresses the idea that reality and language, nature and culture, matter and meaning, are inextricably intra-actively entwined (Barad, 2007: 3). We engaged in a complex reading of individual young people's practices of knowing and doing as evidenced in the material enactments that contributed to, and were a part of, intradisciplinary practices of relational knowing. This itself offers a pedagogic strategy, inviting new ways of teaching based on questions and dialogue, and different ways of perceiving the subjects and the learners.

As STEAM practitioner educators and researchers, we need to look closely at what intradisciplinary practice is and why it matters for future-making education. The "entanglement" of the material has agency of its own. This lies at the heart of Barad's philosophical position of agential realism where we need *to pay attention to matter as well as meaning* as practitioner educators and researcher communities. We need to continually disrupt and uproot the presumptions

upon which siloed subject knowledge is based and rethink how STEAM practices can create novel worlds without imposed constraints on what is possible when we venture into the intradisciplinary knowing between mathematics and the arts. We invite readers to ask what this enables teachers to develop. Our view is that teachers should shift emphasis to rethinking how the material artefacts of learning embody and shape practices and perceptions of knowing things differently. Pedagogic strategies for future-making education also need to recognise the agency of STEAM practice as a way to advance understanding and insights into how young people – the makers of the future – understand themselves in the enactment of and meaning making between mathematics and art. At the mutually constitutive centre of intradisciplinarity and future-making education, the pedagogies pertinent to the arguments presented in this chapter, we end with Ellsworth (2005: 55), who explores a relation among different possibilities:

> In excessive moments of learning in the making, when bodies and pedagogies reach over and into each other, the pedagogical address and the learning self interfuse to become "more" than either intended or anticipated. The instability and fluidity of pedagogy hold the potential for an unknowable and unforeseeable "more", and the actualisation of that potential is what springs the experience of the learning self.

Acknowledgements

We would like to sincerely thank all of the schools and students, but particularly the three South African young people, who participated in this study.

Notes

1 The GMMDC offers annual regional two-day GeoGebra conferences for in-service mathematics educators, which in 2017 emphasised a STEAM education focus, particularly for participants from disadvantaged regions. Dr Kristof Fenyvesi established connections with GMMDC through his experiential math-art workshops. In 2018, to create further awareness about STEAM and math-art connections, together they developed the Math-Art Competition, initially launched across Eastern Cape Province, to encourage pupils and educators from high schools to create art from maths. It is intended that the competition will be conducted on a larger scale in the following years.

2 The Math-Art Competition was advertised through local media and emails to schools, and ran for two months. Flyers and entry forms were handed out at learner programs held after school hours. Currently the math-artworks are in the Bridges Children and Youth Math-Art Collection, and were on show in July 2018 in the Swedish National Museum of Science and Technology during the Bridges Stockholm Conference (www.bridgesmathart.org/bridges-2018).

3 The study is reported in a book chapter by Fenyvesi et al. (2019).

4 Any act of observation makes a "cut" between what is included in and excluded from what is being considered – memories, belongings and attachments to material and visual cultures – in a process that rebuilds, folds and expresses constellations of significance in their lives (see also Barad, 2003; Hickey-Moody, 2018).

5 Some of these math-artworks were incomplete, barely attempted or without a statement of intent, thus not included.

6 These included the aesthetic, cognate, critical, creative, affective, embodied, attitudinal, conditional, material, discursive, emotional and temporal dimensions of mathematics and arts literacies and learning.

7 We use pseudonyms throughout.

8 In her article "Diffracting diffraction", Barad (2014: 177) reflects on the "material conditions of *exteriority-within-phenomena*" (emphasis in original), explaining how entanglements are not *unities* and do not erase differences since they exist not only between two entities or systems (say, insider-outsider) but also within the outsider and insider of oneself, at once bending, converging and interrupting the object of examination in co-constitutive and multiple ways (see also Chappell et al., 2019; Murris & Bozalek, 2019).

9 Barad, in moving away from representationalist beliefs, contests the "excessive power granted to language to determine what is real" (2003: 802) and the representation of pre-existing things, and offers a performative understanding of discursive practices. She adds that performativity, if properly construed, is "actually a contestation of the unexamined habits of mind that grant language and other forms of representation more power in determining our ontologies than they deserve" (802). She suggests that a move toward "performative alternatives to representationalism" shifts the focus from "descriptions and reality (e.g., do they mirror nature or culture?) to matters of practices/doings/actions", thus foregrounding critical questions around ontology, materiality and agency (802).

10 By "discipline-specific cognition" we mean theories, concepts, processes, skills, literacies, knowledges and material and discursive resources made available by individual disciplines. Materiality is related to the physical material and matter, and audiovisual cultures. It may include aesthetic material, cultural artefacts, derived and indicative symbols, place, apparatuses, skills, policy documents or self-reflection notes amongst others.

References

Barad, K. (2003). Posthumanist performativity: Toward an understanding of how matter comes to matter. *Signs: Journal of Women in Culture and Society, 28*(3), 801–831.

Barad, K. (2007). *Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning.* Durham, NC: Duke University Press.

Barad, K. (2014). Diffracting diffraction: Cutting together-apart. *Parallax, 20*(3), 168–187.

Beane, J. A. (2011). Curriculum integration and the disciplines of knowledge. In J. Sefton-Green, P. Thomson, K. Jones, & L. Bresler (Eds.), *The Routledge international handbook of creative learning* (pp. 193–199). Abingdon: Routledge.

Chappell, K., Hetherington, L., Ruck Keene, H., Wren, H., Alexopoulos, A., Ben-Horin, O., … Bogner, F. X. (2019). Dialogue and materiality/embodiment in science|arts creative pedagogy: Their role and manifestation. *Thinking Skills and Creativity, 31*, 296–322.

Collin, A. (2009). Multidisciplinary, interdisciplinary and transdisciplinary collaboration: Implications for vocational psychology. *International Journal for Educational and Vocational Guidance, 9*(2), 101–110.

Colucci-Gray, L., Burnard, P., Trowsdale, J., Cooke, C. F., Davies, R., & Gray, D. S. (2017). *Reviewing the potential and challenges of developing STEAM education through creative pedagogies for 21st learning*. London: British Educational Research Association.

Ellsworth, E. (2005). *Places of learning: Media, architecture, pedagogy*. New York, NY: Routledge.

Fenyvesi, I., Brownell, C., Burnard, P., Sinha, P., Olivier, W., Steyn, C., & Lavicza, Z. (2019). Mathematics and art connections expressed in artworks by South African students. In L. Bresler (Ed.), *On art and science*. Dordrecht: Springer.

Greene, M. (1978). Wide-awakeness and the moral life. *Landscapes of learning* (pp. 42–52). New York, NY: Teachers College Press.

Haraway, D. (1997). *Modest_Witness@Second_Millenium. FemaleMan_Meets_oncoMouse: Feminism and Technoscience.* London: Routledge.

Hickey-Moody, A. (2018). New materialism, ethnography, and socially engaged practice: Space-time folds and the agency of matter. *Qualitative Inquiry* [Preprint]. https://doi.org/10.1177/1077800418810728

Ingold, T. (2018). *Anthropology and/as education*. Abingdon: Routledge.

Murris, K., & Bozalek, V. (2019). Diffracting diffractive readings of texts as methodology: Some propositions. *Educational Philosophy and Theory, 51*(14), 1504–1517. doi:10.1080/00131857.2019.1570843

Murris, K. (2018). Posthuman child and the diffractive teacher: Decolonizing the nature/culture Binary. In Am. Cutter-Mackenzie-Knowledges, K. Malone, & E. Barratt Hacking (Eds.), *Research handbook on childhoodnature: Assemblages of childhood and nature research* (pp. 1–25). Dordrecht: Springer.

Murris, K., & Thompson, R. (2016). Drawings as imaginative expressions of philosophical ideas in a Grade 2 South African literacy classroom. *Reading & Writing – Journal of the Reading Association of South Africa, 7*(2). https://doi.org/10.4102/rw.v7i2.127

Spaull, N. (2019). *Priorities for education reform in South Africa*. Stellenbosch: Stellenbosch University. Retrieved August 13, 2019, from https://nicspaull.files.wordpress.com/2019/01/spaull-priorities-for-educ-reform-treasury-19-jan-2019.pdf

Thomson, P. (2008). Children and young people: Voices in visual research. In P. Thomson (Ed.), Doing visual research with children and young people (pp. 1–21). London: Routledge.

Tsanwani, A., Harding, A., Egelbrecht, J., & Maree, K. (2014). Perceptions of teachers and learners about factors that facilitate learners' performance in mathematics in South Africa. *African Journal of Research in Mathematics, Science and Technology in Education, 18*(1), 50–51.

Wolhuter, C. C. (2014). Weaknesses of South African education in the mirror image of international educational development. *South African Journal of Education, 34*(2), 1–25.

World Economic Forum. (2016). *The future of jobs: Employment, skills and workforce strategy for the fourth industrial revolution*. Geneva: World Economic Forum. Retrieved August 13, 2019, from http://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf