Communications

What is the shape of the Earth?

JUSTIN DIMMEL

In January, Bobby Ray Simmons Junior, an American rapper and music producer known by his stage name B.o.B., was ridiculed across social and broadcast media for a series of tweets in which he shared his belief that the earth is flat [1]. As a mathematics teacher, I read his tweets not as an attack on science but rather as a pedagogical challenge: what direct evidence does a surface dwelling creature like me, without satellites or rocket ships, have about the shape of the Earth? The fact that the Earth is roughly spherical is not in dispute. But what is the harm in looking carefully at B.o.B.'s statements and using them as a basis to argue that the Earth can't be flat?

For something that is supposedly learned in elementary school, it was surprising that responses to B.o.B. tended toward dismissal rather than explanation. News stories that reported about B.o.B.'s tweets generally avoided the questions he raised about our visual experience of the horizon [2]. Even astrophysicist Neil deGrasse Tyson, who may be considered the US scientific communicator-in-chief, failed to provide an explanation in his response to B.o.B. [3].

Rather than use his own knowledge of physics to offer B.o.B. a reasoned argument about the shape of the Earth, Tyson instead warned against the "growing anti-intellectual strain" in the US that may be "the end of our democracy." He also spoke out against the harm that can be caused when people with influence over others promote falsehoods. I agree with Tyson that the rise of antiscience concerns us all. But I was disappointed that the scientific content of Tyson's response to B.o.B. was a single declarative sentence: "It's a fundamental fact of calculus and non-Euclidean geometry [that] small sections of large curved surfaces will always look flat to little creatures that crawl upon [them]."

This statement refers to the locally Euclidean property of topological manifolds. Tyson did not elaborate on how this fact might help B.o.B. recognize that the Earth must be roughly spherical. In fact, if the Earth were shaped like a torus, a cylinder, or a generic blob, it could still have large curved sections that look flat to little creatures crawling upon it. The locally Euclidean property is not sufficient to prove that the Earth is a sphere. What's more, it is irrelevant to B.o.B.'s claims and questions. Tyson, in his impassioned defense of scientific knowledge, missed an opportunity to demonstrate how scientific reasoning can be used for education.

The claim that the Earth is flat can be treated as a misconception, on a par with misconceptions about what causes the Earth to experience seasons or what causes the moon to exhibit phases. And given the challenges of relating the (global) geometry of spheres and lines to our (local) visual experience of the world, it is not unreasonable for someone to come to the conclusion that the earth is flat. That B.o.B. tweeted his attempt at making sense of the evidence available to him is no reason for him to be scorned. What opportunities for learning do we find if we take B.o.B.'s tweets seriously and attempt to meet his challenge with scientific reasoning?

B.o.B.'s tweets focused on his visual perception of the shape of the Earth. The tweets that give the clearest view into his rationality concern the experience of the horizon: "No matter how high in elevation you are [...] the horizon is always eye level." It's hard to know exactly what B.o.B. means by this. One interpretation is that he is claiming that viewed from any scale (*e.g.,* on the ground, in a building, on an airplane, from space), the curvature of the earth is undetectable. This interpretation is tantamount to the claim that the true shape of the Earth has the property that it is always indistinguishable from a plane. Such a reading is consistent with other B.o.B. tweets that used photographs of the Earth at various heights to show that it looks flat. In several of these tweets, B.o.B. asks for people to explain how it is possible for the horizon to always—that is, regardless of increases in an observer's height—appear to be a straight line, even though the surface of the Earth is supposedly curved [4]. Thus, a more charitable interpretation of B.o.B.'s tweets would be the following argument: whatever the shape of the Earth is, it has the property that it is not only *locally* flat but also globally flat; thus, the Earth can't be spherical. B.o.B.'s conclusion that the Earth is flat is consistent with what he believes the evidence shows.

B.o.B.'s conclusion is incorrect, but that is no reason to deride or dismiss him. It is said in science and mathematics classrooms "there are no stupid questions". Yet the reactions to B.o.B. illustrated the courage it takes to press for an explanation of something that is supposedly obvious.

If we were to take B.o.B.'s challenge seriously and attempt to explain the shape of the Earth in terms he might be willing to accept, how could we proceed? A good place to start is with our shared experience of the horizon. It is natural to begin here because B.o.B. admits that there is such a thing as a horizon. The existence of a horizon, literally a boundary circle, means there is a limit to how far away we can see. But if the Earth were flat like a plane, why would there be any such limit at all? Figure 1 and Figure 2 (both overleaf) show different limiting cases of the apparent height of an object as an observer moves away from it.

On a flat Earth (Figure 1), as one moves away from an object, its apparent altitude above the ground decreases. But as there is nothing to impede lines of sight to the object, there is no point at which the object would set below an observer's horizon. On a spherical Earth (Figure 2), as one moves away from an object, its apparent altitude also decreases. Only now, there is a point beyond which the object will no longer be visible. It will set below the horizon, when lines of sight to the object are blocked by the curve of the Earth. Thus, that there is any horizon at all and that the horizon is experienced the same way wherever we are on the surface of Earth is evidence that the Earth is roughly spherical.

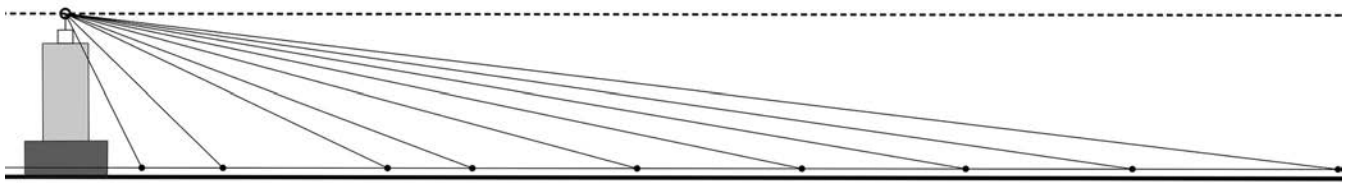

Figure 1. On a plane, lines of sight to distant objects are never impeded. The apparent height of an object would decrease as one gets further away, but there is no horizon.

That the limit of an Earth creature's field of view is geometrically determined can be visibly experienced at some places where there is a clear view to the true horizon. If the conditions are right, one can see that the distance to the horizon depends directly and only on the height of one's eye above the ground. Here are two experiments to try that empirically explore the distance to the horizon.

> **Experiment 1.** Visit the seashore, preferably someplace where there are islands or shoals in the distance, and look to the horizon. For full effect, bring a stepladder. Start by lying on your stomach. Look out as far as you can see, toward the horizon. Now stand up, and look out again. Finally, climb to the top of the ladder and look again. Repeat this process several times. As your height changes, what happens to the distance away that you can see?

> **Experiment 2.** Once again stand at the seashore, only now with binoculars of varying strength. With your unaided eyes, look to the horizon. Next, use the lowest setting of the binoculars and look to the horizon. Finally, use the highest setting of the binoculars and look to the horizon. As you move from unaided eyes to the highest magnification, how much further away can you see?

By performing the first experiment, one could observe that the distance to the horizon changes as one's height increases, from less than 1 mile (while on one's stomach) to more than 4 miles (while standing atop a 6 foot stepladder). By performing the second experiment, one could observe that greater magnification can bring distant objects into sharper focus but will not increase how far out one can see (so long as eye height stays fixed). A natural question one might ask, once these initial observations have been made, is: how far away is the horizon? That is: what is the line-of-sight distance to the last visible point? What is nice about this question is that it has a purely mathematical solution. It is an example of the inherent, ancient connection between Euclidean geometry and our visual experience of the world.

I used experiments like these with high school students in my work as a mathematics teacher. We conducted the experiments on a sand bar where the alternating blue and green bands of the Caribbean helped to provide a reference for gauging how much ocean was visible from a given height. The purpose of the experiments was to connect students directly to some of the earliest evidence about the shape of the world.

The results of these experiments may not be enough to convince a skeptic that the world must be spherical. However, were the skeptic to conduct them with an honest, open mind, he or she would at least have to recognize that the experience of a horizon poses a challenge to the idea that the Earth could be flat like a plane. It may look flat at any height, but the total amount of the Earth that is visible increases as eye height increases. One of the simplest ways to explain this uniform change in distance to the horizon is that the Earth is roughly spherical. A skeptic need not accept this conclusion, but whatever the skeptic concludes about the shape of the Earth has to be consistent with the fact that, whatever one's location on or above the surface of the Earth, there is a limit to what one can see that depends directly on the height of one's eyes.

We know more about the world now than at any moment in human history because of the ongoing projects of science and mathematics. I offer a serious reading of the challenge in B.o.B.'s tweets not in the spirit of denying known facts, but in the spirit of embracing the power of mathematical reasoning to make sense of our experience of the world.

Notes

[1] See 'I didn't wanna believe it either': Rapper BoB insists the Earth is flat. *The Guardian,* 26 January 2016. B.o.B. has since deleted some of the

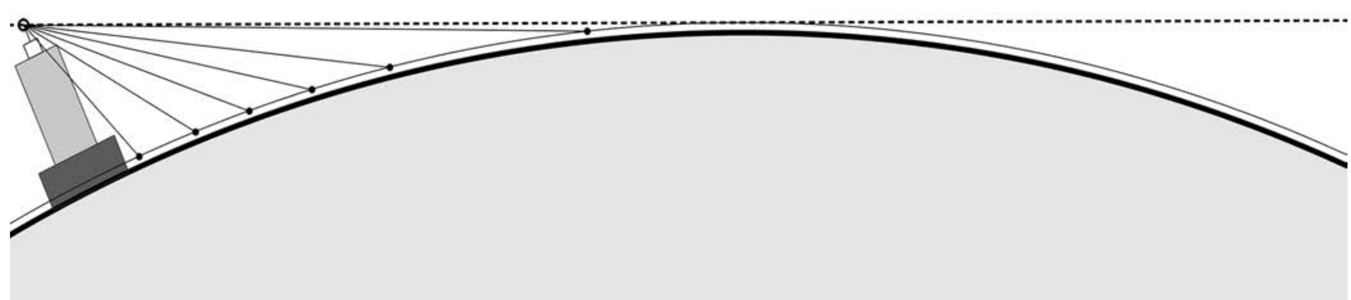

Figure 2. On a sphere, an object eventually sets below an observer's horizon—the point beyond which lines of sight are blocked by the curve of the Earth.

tweets, though records of what he tweeted are available in news archives, such as at www.theguardian.com/music/2016/jan/25/bob-rapper-flat-earth-twitter

[2] Examples of such stories may be found at: www.cnn.com/2016/01/26/entertainment/rapper-bob-earth-flat-theory/ and www.washingtonpost.com/news/answer-sheet/wp/2016/02/02/why-in-the-world-would-rapper-b-o-b-think-the-earth-is-flat-a-quick-science-lesson/

[3] Tyson was called in for a "science emergency" on Larry Wilmore's *The Nightly Show* (youtu.be/XHBZkek8OSU)

[4] An example of one such tweet may be found at twitter.com/bobatl/status/691411463051804676

Ableism and the ideology of merit

ROSSI D'SOUZA

In a communication in FLM36(1), I discussed a teaching episode in which my students in a school for the blind explored properties of odd and even numbers and developed novel definitions (D'Souza, 2016). In that session, despite trying to get the students to construct their own mathematical ideas, I kept trying to lead them to arrive at the standard mathematical definition. However, I was uneasy with this approach, because, as Mukhopadhyay and Roth (2012) have pointed out:

> Even though constructivist theory emphasizes the personal construction of knowledge, actual mathematics education practices generally aim at making students construct the "right", that is, the canonical practices of mathematics—not realizing that for many, this may mean symbolic violence to the forms of mathematical knowledge they are familiar with, and that the standard processes typical of mathematics education contribute to the reproduction of social inequities. (p. vii)

Some days later, I planned to quickly revise the topic of odd and even numbers and move on to another topic. However, we ended up again debating the evenness of zero. The students now insisted that zero is a special number that should not be placed in the broad category of even numbers. Their final winning argument was that if we keep dividing even numbers like 2, 4, 6, 8, … by 2, we finally reach an odd number. However, this does not happen with zero. They were right. Now that they had constructed valid, yet "not right" mathematics, my former uneasiness vanished. But it was replaced by another problem.

On narrating this incident, some of my colleagues were uncomfortable at the thought of "poor blind children" having the "wrong" concept. "What if they give such answers in their exams?" and "You finally told them the correct definitions, right?" were standard responses. I "needed" to tell my students the "correct" definition of even and odd numbers, albeit with a disclaimer about the nature of formal curricular mathematics, lest they raise questions or present alternative mathematical opinions in future mathematics exams, and fail.

Ideology of merit

I argue that ideology, and specifically what I term as the ideology of merit, played a significant role in my addressing my students and even the reactions from colleagues. Borba and Skovsmose (1997) describe ideology as "a system of beliefs which tend to hide, or disguise, or filter a range of questions connected to a problematic situation for social groups [...] obstructing possibilities for identifying and discussing the nature of the 'crisis'" (p. 17). Discussing mathematical ideologies, Richard Noss (1994) writes of the "overwhelming temptation to view the subject matter as given, inevitable, *natural*" and the "tendency for ideologies to become 'common sense', applied without explicit intention and [...] an accompanying tendency to see the surface reality of this as their unalterable bases and causes" (p. 2). I employ these descriptions to present the notion of the ideology of merit, by which I mean the underlying (conscious or unconscious, explicit or implicit) worldview in which "merit" or "excellence" is taken to be the main driving force for learning a body of knowledge. And, in mathematics education in India, "excellence" too often refers to how well a student can follow prescribed (or other) procedures to solve *given* problems in order to get the one given correct answer to each problem, thus limiting the opportunity for students to investigate answers or ask their own questions. Our investigation of odd and even numbers was restricted through this ideology of merit.

One of my students once raised the question, "If mathematics is all in the head then why is there an emphasis on the paper and pencil?" On another occasion when I asked my students what was their most difficult topic in mathematics, they replied, "Steps". They could solve mathematical problems, but had to show all the in-between steps on paper, lest they be deemed less meritorious.

We often do not know what our ideologies are; they can only be revealed by examining our actions. For example, if we profess to have an ideology of peace and non-violence, but go to school and regularly beat our students if they misbehave, then our actual ideology is not non-violence. Similarly, we may profess an ideology of believing in the importance of an inquiry method of teaching, but then not allow students to ask questions—especially systemic questions. By analysing our actions, we can try to understand our ideologies and also work towards changing them. When our ideology is consistent with the ruling or dominant ideology, we tend not to realize that we have it. By opposing the ideology of merit in this communication, I advocate trying to adopt an anti-merit ideology.

Merit is interdependent with what Teltumbde (2008) refers to as hyper-individualism, of which he says:

> It atomizes society into discrete individuals, each against the rest of them [...] It legitimize[s] the right of (the) strong to exploit the weak [...] It establishes the inevitability of the "underclass" of those who cannot participate in competition, which should survive only as subservient to those who are competitive [...] Neoliberalism believes that the world should be [an] enjoyable place for those who deserve it and should be rid of those who do not. (p. 22)

By categorizing the victims, merit rationalizes the exploitation of oppressed castes [1] and disabled people. It tells them that they too can enjoy the privileges of winning the competition by working harder (or doing whatever they are "differently abled" at). But how can you have winners without having losers? If one's "achievement" is defined in relation to others, it can only be at the expense of somebody's failure. Irrespective of how hard people work, merit ensures that most people are losers. And further, the criteria for winning are decided by the dominant, privileged groups. It is not coincidental that most losers are from oppressed groups. And they may be told that if they had just worked harder they would have succeeded like the deaf-blind Helen Keller or the Dalit, Eklavya.

Ableism, caste and "content"

An ideology of merit also reinforces Ableism, which Campbell (2001) defines as:

> A network of beliefs, processes and practices that produces a particular kind of self and body (the corporeal standard) that is projected as the perfect, species-typical and therefore essential and fully human. Disability then is cast as a diminished state of being human. (p. 44)

Ableism is often spoken of as being synonymous with the oppression of disability—the discrimination faced by people with disabilities. The concept of Ableism is similar to the idea of deficiencialism coined by Marcone (2015), which he refers to as "normal people defining abnormal people" (p. 132). I would argue that designing a mathematics curriculum that presumes that students can see, and learn better if content is taught in a visual manner, is an instance of Ableism.

But there's more to Ableism that such discourses do not sufficiently convey. Although "deficiencialism" aptly connotes having less (than "normal"), it says little about what "having more" could entail. The concept, "Gifted" carries this connotation of "having more", but is unfortunately celebrated as an individual feat, even though giftedness (being blessed with more) can exist only in relation to deficiency (being cursed with less). So if we speak of giftedness as being inherent (not a socially constructed problem), we imply that so is deficiency.

In relation to caste, Somwanshi [2] has argued that "caste is a structure that includes 'everyone' […] oppression can't exist without someone getting undue privilege". In a similar sense, Ableism includes everyone, not just disabled people. Ableism is not just the oppression of disability, it is also privilege.

For example, Skovsmose (2016) discusses how "difficulties arise from the relationship between Braille and mathematical symbols" (p. 3). We should relate these difficulties to *our privileges,* that arise from the relationship between dominant languages like English and mathematical symbols. "Mathematical symbols" does not mean visual-English symbols.

Ideology (and Ableism in mathematics education) is not limited to the (for example, visual) "form" of presenting mathematical ideas. Even the "content" carries ideology. Many students by their very dis/abilities, background and cultures find it much harder or impossible to grasp or construct the standard "content", and thus fail. Sowjanya [3] argues that "In our society, knowledge is not power but what constitutes knowledge and becomes acceptable to the upper-castes determines power. Hence the current education system could successfully prove dalits to be unmeritorious". Thus, in India, someone possessing "important" (mathematical or other) knowledge is very likely to come from an upper caste family.

Rather than addressing the systemic contradictions inherent in the caste system, however, many people accuse Dalits of perpetuating the caste system for relying on "reservations" (affirmative action) [4] rather than meritocracy.

Final words

My blind school experiences indicate that there is an alternative to the conservative "content" view of mathematics. My student's question about the emphasis in mathematics on paper and pencil is significant, for example. This blind student was resisting Ableism in mathematics education by asserting himself as a mathematics doer who is denied the right to self-determination in mathematics through the lack of validation of his form of mathematics. The alternative is to focus on the "process", rather than "content", leading to a broader and deeper learning, even of that "content". We need to create conditions where children question mathematical "facts" and can form their own mathematical ideas rather than lead them to "accept" why the dominant mathematical content is the "right" mathematics. When students challenge dominant mathematical concepts, such as the standard definition of even numbers, they perform acts of resistance against oppressive ideologies. We need to nurture their resistance through solidarity.

Notes

[1] The Caste System, which is still practiced in India and inherent to the Hindu religion, is an oppressive system of hierarchical social stratification premised on the enforcement of endogamy and family inherited professions which include manual scavenging, and untouchability. Caste (which I use synonymously with Brahmanism, to highlight the oppressor caste) makes it hard for women and non-Brahmins to access education. *Annihilation of Caste* by B. R. Ambedkar (a leading figure in the Anti-caste movement) is an instrumental text on caste. Gail Omvedt's writings provide a (historic) overview of the topic. http://roundtableindia.co.in/ is an extensive online resource for current writings on caste by young dalit-bahujan writers.

[2] How can we exclude the storyteller from the story being told? *Round Table India,* 7 April 2015. Retrieved from: http://roundtableindia.co.in/index.php?option=com_content&view= article&id=8135 on 17 October 2016

[3] Death of merit or merit of death. *Round Table India,* 25 January 2016. Retrieved from: http://roundtableindia. co.in/index.php?option=com_content&view=article&id=8447 on 17 October 2016

[4] "Reservations" is a term used for the affirmative action in which some college seats and government jobs are reserved for Dalits, Tribals, *etc.*

Acknowledgement

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From the archives

Editor's note: *The following remarks are extracted (and slightly edited) from an article by Christine Keitel (1986), who died earlier this year. The article, which was based on Keitel's plenary address at the 38th annual meeting of CIEAEM (Commission internationale pour l'etude et l'amelioration de l'enseignement des mathematiques), appeared in FLM6(3).*

We cannot deal with secondary school mathematics without considering the impact and role of computer technology for, and in, and beside mathematics education.

This does not need to be repeated here. A point, however, to which I would like to draw some attention, is the relation of both computer education and mathematics education to the field of "social needs" demands. By "social needs" demands I understand here the pressures urging school mathematics to comply with the needs for certain skills and abilities required in social practice. Mathematics education should qualify the students in mathematical skills and abilities so that they can apply mathematics appropriately and correctly in the concrete problem situations they may encounter in their lives and work. Conversely, social usefulness has been the strongest argument in favour of mathematics as a school discipline, and the prerequisite to assigning mathematics a highly selective function in the school system.

[...]

Viewing the role of social needs in and social control of our present day mathematics education, and confronting it with what we could imagine to be meaningful mathematics education, it is obvious in my opinion that these conceptions are so profoundly contrary to each other that any attempt at reconciling them would inevitably result in obstructing the success of either conception. Indeed I would suggest we ought to consider how far this basic dichotomy in our school mathematics might be the source of many traditional difficulties and failures, which we persistently try to overcome, and which obstinately remain. Isn't it this schizophrenia [*sic*] which makes us tell the student that everybody has a good chance to learn mathematics, knowing at the same time that examinations by their very construction have to ensure a certain percentage of failures? Isn't it schizophrenia that we invite them to do creative mathematics and yet let them work for examinations? I think that children who suffer from school mathematics are not really suffering from mathematics but from this schizophrenia, which affects them quite considerably.

Keeping this in mind, let us turn back to the competitive relation of mathematics education and computer education. It is astonishing to realize that, quite differently from the case of mathematics education, there seems to be a particular affinity of computer education for what we may call the social needs and control approach. [...] All the more important processes which pertain to understanding cannot be done by a computer (although the computer may be used there in a subordinate function): the processes of structuring the problem context, of explicating an instrumental level of treatment, of translating to and fro between different levels of formal explicitness until eventually a problem solving model develops; and again the interpretation of the solution at the level of concrete significance, and the feedback to the levels of mathematical and reality understanding—in none of this can the computer replace the applier's brains.

On the contrary, in our model of skill-oriented application, where understanding is of no or less importance, the whole process, except for the identification of the problem type, can be carried out by the computer. And if we may imagine that in a restricted field of application the problem-solving pattern could be chosen by the computer as well, the application shrinks to the simplest stimulus-response bond: one has but to push the button. This then requires neither mathematics nor informatics—except for the computer specialist, who needs both.

May I add here—though this is actually another topic—that the computer need not only be employed for reductive purposes. We could as well imagine placing the computer in the center of a problem-structuring process as an agile turntable allowing speedy reflections between formal mathematics and concrete reality. [...]

This is not a model of computer education, but of integrated mathematics education and computer education, and could moreover integrate mathematics education with other disciplines such as geography, economics, biology, social sciences, *etc*., as well.

The affinity between computer education and a traditional needs-and-control approach, contrasted with the problems mathematics education proves to have in this domain notwithstanding all reform efforts, has of course attracted the attention of those representatives of society who wish to keep the school on the tight rein of their demands, and of those within school who take it as the highest aim of education to comply with these demands. And in fact we register that the interest, and trust, of the advocates of what they call usefulness are rapidly shifting towards computer education. And that certainly frightens many of us. What can we infer from our previous findings as perspectives on this situation?

As my conclusion I shall try a few answers, which are, however, very tentative and maybe partly utopian. They do not pretend to certainty.

The disease of mathematics education in my view is the inert dichotomy between a direct needs obligation and the claims of cognitive development. If mathematics education keeps as it is, we shall continue not achieving our goals with respect to cognitive development, and the instruction for usefulness will be inferior to that offered by computer education. As a consequence, mathematics education will lose its place in the core of the curriculum. We shall come generally to a situation similar to that in England now at the secondary level: a sophisticated, highly demanding mathematics course for those who continue their studies, and next to nothing for the rest. One could imagine a free mathematics course alongside the other one. It is a seductive idea, but clearly, in practice it would not stand up to the selective course, and would rapidly degenerate into inferiority.

The only alternative for mathematics education, then, as far as I can see, is to settle the old dichotomy between social and cognitive demands. First we shall have to clarify our relationship to social needs. The opportunity is good: for the first time the grip of social demands, shifting to computer education, is loosening on mathematics education. Secondly we shall have to clarify our relation to computer education in the sense of a division of labor. The result should be that mathematics education will not be predominantly responsible for a direct response to social needs. Thirdly we have to strive for other examinations, which do not force us into the wrong direction. Our direction is indirect, mediate, usefulness. It is the same kind of usefulness as that to which vernacular literature education is committed: at the secondary level, other than in spelling, grammar and orthography, nobody would claim to control learning achievements by the type of examination tasks we have in mathematics. If we manage to attain a position similar to that which vernacular literature education at the secondary level has today, we may have overcome our present crisis.

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What is it that makes classroom experiences worthwhile? This formulation hides too much of the deep etymological inheritances of such a question: what makes a classroom experience worth, not simply zero-sum school-grade exchange, but *while*? What makes some experiences worthy of rest and repose, worthy of returning, worthy of tarrying and remembering, of taking time, of whiling away our lives in their presence?

Worth *while* instead of simply worth cramming-as-time-runs-out-for-upcoming-examinations speaks, therefore, to a sense of temporality. “While” and what might be worthy of it is about time.

One can’t while over disconnected fragments. They don’t ask this of us and will reject any such efforts at whiling.

There is thus a hidden ontology here, that *to be* worthy of while means not being disconnected and fragmented and distanced, manageable object[s], but to be lived with [...] Living disciplines full of topics that we are living in the midst of and to which we [belong] in contested and multifarious ways—these things are worthwhile, worth whiling.

Jardine, D. W. (2012) *Pedagogy Left in Peace: Cultivating Free Spaces in Teaching and Learning,* pp. 173-175. London, UK: Continuum.
