7 A decolonial science education

How do we move forward?

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Introduction

The call for decolonization in the context of science education elicits various responses from academics in the sciences. The first is incredulity followed by a rejection that the idea is even worth discussing. The second is a populist leap into attempts to include local knowledge content without any real critical engagement. The third is a recognition that there may be something to the call for decolonization, but a sense of being overwhelmed by what might actually be required to decolonize in any meaningful way (Costandius *et al*., 2015). Both the first and second approaches tend to be knee-jerk responses and both are potentially problematic albeit in different ways. In Adendorff and Blackie (2020) we offered an analysis of these positions using the dimensions of Specialization and Autonomy from Legitimation Code Theory (LCT). Helping academic scientists into the third space where it is possible to recognize that there may be merit to engaging with the conversation has been discussed in Chapter 6 of this volume. It is likely that this chapter will be received with confusion by some outside science education as to why such painfully slow steps need to be taken. It may simultaneously be viewed as a profound, paradigm shifting argument from those within the sciences inclined to engage with the conversation. In reading this chapter, we ask you to take cognizance of your own starting point while understanding that our goal is to facilitate the process in science; our intended readers are primarily academic scientists.

The task in this chapter is to examine where we need to begin the journey to decoloniality. In the humanities, the starting point may be the curriculum content itself. We argue here that in the physical or natural sciences the point of departure is not the curriculum content itself but the Western idea of the primacy of the autonomous individual. The invitation for academic scientists is to begin to pay attention to the diversity of human beings sitting

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in their lecture theatres rather than the far simpler 'blank slate' upon which scientific understanding is to be imprinted.

Is science socially neutral?

We turn to the work of Maldonado-Torres (2016) who writes about coloniality of power, coloniality of knowledge and coloniality of being.[1] He argues that the modern/colonial conception of knowledge comprises three major elements: subject (and subjectivity), object (and objectivity), and method (and methodology). Whilst there are other ways of conceiving of knowledge, there are no other ways to conceive of *scientific* knowledge. However, situating power, knowledge and being as three interrelated structures which potentially foster and support coloniality gives us an entry into the conversation within science and science education.

We need to begin by acknowledging that legitimate knowledge in science is determined primarily through the manner in which it is produced. There is a direct link between the development of precision instruments in Europe and the establishment of scientific fields. Chemistry only emerged as a scientific field in the nineteenth century with the development of accurate balances which could measure precise masses of substances (Fabbrizzi, 2008). This enabled the development of technology which fueled the first industrial revolution and with this the substantial increase in British colonization. These things are all inextricably linked. Thus, no reimagination of science will decouple the scientific method from the technology of measurement which is strongly associated with Western Europe.

The fact that an experiment performed in a laboratory in Mumbai can be reproduced reliably in Vancouver is taken as fundamental to natural science (Goodman *et al.*, 2016). This reproducibility is an essential part of the scientific method and is a major element of ensuring validity. In these terms, the experiment transcends culture. Provided each scientist is sufficiently trained in the skills required to both carry out the experiment and to analyze the data produced there should be no difference in the outcome of the experiment, regardless of where it is performed. To this end, science can be seen as being 'objective' in the sense that the cultural background of the person performing the experiment is irrelevant.

Yet, more recent scrutiny has shown that this concept of reproducibility can be less reliable in particular instances than the ideal would suggest (Goodman *et al*., 2016). Furthermore, the meaning of reproducibility varies across the natural and physical sciences. Nonetheless, it is upon this concept that the 'objectivity' of science rests. However, it is clear from the work of Kuhn (1977) that there is a distinct difference between the objectivity in the consensus position of the scientific field and the position held by an individual scientist. The individual scientist is profoundly influenced by the mental paradigm into which they were inducted. Boas' notion of sound blindness is a useful illustration. Sound blindness is the term used to describe the observation of anthropologists describing sounds made in foreign languages. These anthropologists were substantially influenced by their own native tongue (Boas, 1889; Roepstorff *et al*., 2010). They could not hear some variations in speech in foreign languages precisely because they had been conditioned to hear the particular variations inherent to their mother-tongue. Scientists are similarly shaped by the paradigm of theory through which they intellectually entered the field (Kuhn, 2012). Thus, we must be careful not to uncritically confer the objectivity of science upon any individual scientist (McComas, 1996).

The subjectivity indicated by both Boas and Kuhn is complemented by the recognition that when one begins to explore the history of any particular science it is clear that the experience of the scientist plays more of a role in determining what should be explored and what counts as legitimate knowledge than the current rhetoric of the objectivity of science allows. A simple example of this was the variety of experiments performed to ascertain the age of the Earth. The current measure the age of the Earth was determined using the half-life of radioactive elements (Burchfield, 1975). The internal consistency between different combinations of isotopes means that the answer is fairly well determined. Yet, at the turn of the twentieth century radioactivity itself was barely known and the discovery of the neutron which accounts for the isotopes was still decades away. The problem had presented itself through Darwin's *Origin of the Species* (1859) and Lyell's *Principles of Geology* (1853). It was clear that 'deep time' was necessary to explain both the biological variation and the geological stratification which was so evident. Several scientists stepped up to find an answer this question. Two examples serve to illustrate the point. Kelvin, knowledgeable in thermodynamics, calculated the age of the Earth to be between 20 and 100 million years old. He used the heat transfer between the Sun and the Earth, and transfer within the Earth itself. Alas, the absence of knowledge of plate tectonics, nuclear fusion and radioactivity meant his calculations were fatally flawed (Burchfield, 1975). Joly likewise turned to a subject he knew about. He used the concentration of sodium in sea water to offer an estimate of 80–100 million years (Joly, 1900), the logic being that the sodium had come from rocks through erosion and had thus increased in concentration over time. Again, some of his assumptions turned out to be false (Macdougall, 2009).

The point here is that a major question had arisen from new scientific data and these scientists tried to solve the problem using the intellectual resources at their disposal. The methods they used were well-known and both Kelvin and Joly would probably have been capable of reproducing the procedure presented by the other, but the creation of a possible solution was individual to each scientist. Joly would not have used thermodynamics and Kelvin would not have used sodium concentration. It is at this level that science is deeply influenced by the experience of the individual scientist and, thus, both subjective and highly creative (McComas, 1996). The scientist will approach a problem with their personal lexicon. The verification of their experiments by the scientific community then pulls the data generated and the conclusions drawn into greater objectivity (Kuhn, 1977).

Using the epistemic plane to describe scientific training

Our purpose in this chapter is to examine scientific training so that we can uncover what decolonization may look like in the natural sciences. Drawing on the Specialization dimension from Legitimation Code Theory (Maton, 2014), science and science education may be considered as being a claim about something (*epistemic relations*) and made by someone (*social relations*). We discuss this in detail later in this chapter. At this point we shall explore *epistemic relations* in more detail. Against the backdrop of the example of Kelvin and Joly trying to solve the problem of the age of the Earth, we turn more broadly to the training of scientists using the *epistemic plane*, as shown in Figure 7.1. Epistemic relations refer to practices which may vary both in what they relate to (*ontic relations*) and in how they relate (*discursive relations*).[2] Both ontic relations and discursive relations can vary in strengths along a continuum. Bringing those two strengths together gives what are termed in LCT, *insights* (Maton, 2014). There are an infinite number of possible strengths, but LCT also identifies four key insights, as shown in Figure 7.1.

Situational insights can be understood as procedural pluralism, meaning there is more than one acceptable way to solve a problem. Practices expound strong boundaries around legitimate objects of study but weaker boundaries around which approaches one can legitimately take to address those objects (Maton, 2014). That is, the problem is clearly defined but multiple solutions could be acceptable. This is illustrated in the different approaches taken by Joly and Kelvin described earlier to solve the same problem.

Purist insights strongly bound both legitimate objects of study and legitimate ways in which the study is carried out (Maton, 2014). For example, a PhD project in chemistry will require a well defined object of study recognized to be a chemical problem, will require the use of methods which are recognized as valid to solve this particular problem and will need to be described in a manner consistent with established literary conventions of chemistry.

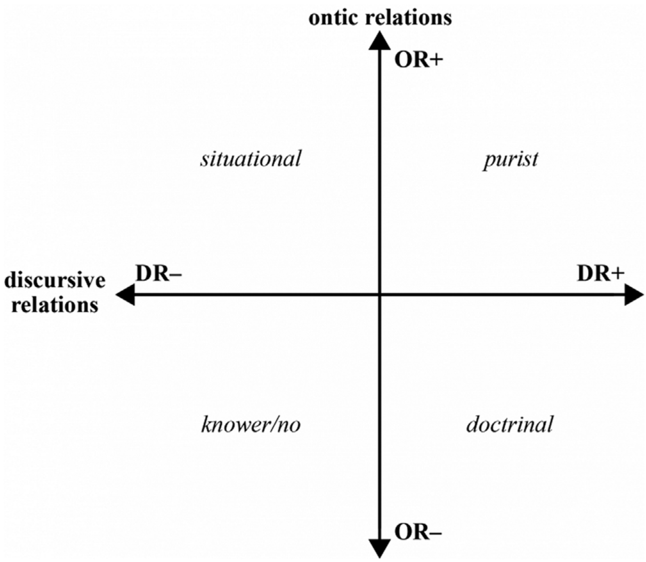

Figure 7.1 The epistemic plane (Maton, 2014, p. 177)

Doctrinal insights can be understood as methodological dogmatism, meaning only specific, well defined methods are acceptable as legitimate. The approach used is strongly bounded but legitimate objects of study are relatively weakly bounded (Maton, 2014). Here one is demonstrating mastery of a method but any object to which that method may legitimately be applied is acceptable. The focus in scientific training can be narrowly constrained to mastery of the method (stronger discursive relations) whilst omitting details of the constraints of application (downplaying ontic relations). Thus, one can master the method but not necessarily understand how it may be applied to other problems (Engelbrecht *et al.*, 2005; Potgieter and Davidowitz, 2011). This tends to be the level of most of science education at an undergraduate level in South Africa. The student has sufficient pattern recognition that they can go through the steps of 'solving' a problem presented in a familiar format. However, they may have no real grasp of the underlying principles, or indeed, any sense of the limitations of the method. In terms of the age of the Earth example described earlier, when it is taught, radioactive decay will be presented as the gold standard of determination of age. No other method would be deemed acceptable. However, this method is only applicable to things which are not living. To extend the example, a student, seeing the application of the method using radioactive carbon to the

Shroud of Turin (made from cotton cloth where the radioactive carbon content is fixed), may try to apply it to aging of the Giant Redwoods which are older. However, the trees are still living and carbon is being exchanged with the environment, therefore the radioactive carbon content is being continually refreshed. This means the method could be faithfully applied but the answer generated by the data will be inherently erroneous.

Knower/no insights occur when neither legitimate methods of inquiry nor legitimate objects of study are constrained (Maton, 2014). In science this insight can be employed when a new field is emerging – such as the field of inquiry which arose out of the question of the age of Earth. Initially, the object of the study and the methods used were entirely open. Kelvin's object of inquiry was the temperature of the Earth using methods from thermodynamics, and Joly's object was the concentration of salt in sea water using methods from solubility studies. The object of study in an emerging field requires both a weakening of the boundaries around what can legitimately be studied and a weakening of boundaries around the manner in which the study should be carried out. As the field matures it is likely that ontic relations and/or discursive relations will strengthen.

Drawing from the context of teaching organic chemistry at a tertiary institution one way of understanding science education can be as movement around this plane. Novice students begin in the knower/no insight. At the beginning of their study, they have little sense of the bounds of a particular subject or of the manner in which knowledge is or can be constructed. The journey begins by learning some of the procedures which are acceptable thereby entering a doctrinal insight, but they may be unaware of the constraints of application of those procedures (DR is strengthening but OR is not yet visible to the student). As time goes by, they learn some of the ways in which the knowledge field is carved into sub-fields and herein purist insights begin to emerge (OR becomes visible and begins to strengthen). And finally, they are presented with a problem which they must be able to identify within a specific knowledge area (OR is strengthening) and then solve though applying diverse methods (DR is beginning to weaken), thus moving towards a situational insight. As discursive relations weaken, so the use of individual creativity may increase.

In the example of the age of the Earth problem it can be argued that both Lord Kelvin and Professor Joly began with a *purist insight*. That is, they were both experts in using a particular set of well defined procedures (DR+) to solve problems within a well defined knowledge area (OR+). The new problem pushed them into a *situational insight* where a plurality of methods could be applied to a clearly defined problem (weakening discursive relations). In engaging with the problem, it became clear that the assumptions which both had to make to apply the procedure faithfully meant that they were moving out of their clearly bounded field (weakening ontic relations). Hence, they were tipped inadvertently into a *knower/no insight*. At this point, both Joly and Kelvin made errors based on their assumptions. Nonetheless, both men were in a position to state the assumptions that they had made because they had already been trained in a way which made recognizing the limits of their experiments clear.

The trained scientist may embark on an entirely new field of study which requires the development of novel methodologies. Nonetheless, the training they would have been through will profoundly influence their manner of engagement with the new field. In other words, there is a degree of personal formation that happens in the process of training the scientist. Thus, becoming a scientist is not just about the appropriation of knowledge (epistemic relations), it also impacts one's way of being in the world (social relations). We will now turn to the *specialization plane* from LCT to explore the interplay between epistemic relations and social relations.

Why is the human person overlooked in science education?

Specialization from LCT allows us to see that what it is to be 'educated' in different knowledge areas is substantially divergent for good reasons. Specialization distinguishes between epistemic relations (ER) and social relations (SR) (Figure 7.2) (Maton, 2014).

In the natural sciences, specialized knowledge, procedures and skills are often emphasized as the basis of knowledge claims (relatively strong epistemic relations, ER+) – and one's personal and social attributes are downplayed as the basis of knowledge claims (relatively weak social relations, SR−). Thus, the natural sciences tend to typically (though not always) represent different forms of a 'knowledge code'. The reverse tends (but again not always) to be true in many humanities subjects: specialized knowledge, procedures and skills are relatively downplayed (ER−) and personal attributes are emphasized (SR+) – a 'knower code'. It is important to note that there is no one 'ideal' form of any of the codes represented on the plane (Figure 7.2) as there is infinite variation of epistemic relations and social relations both across and within disciplines.

Returning to the primary consideration of this chapter – science education and decoloniality – we find a 'code clash' occurring. A 'code clash' occurs when practices exhibit different bases of legitimacy (Maton, 2014). Decolonial arguments, typically situated in a knower code, are used to critique science. Importantly this code clash is also responsible for the inability of many academic scientists to see the relevance of decolonization to science and science education (Adendorff and Blackie, 2020).

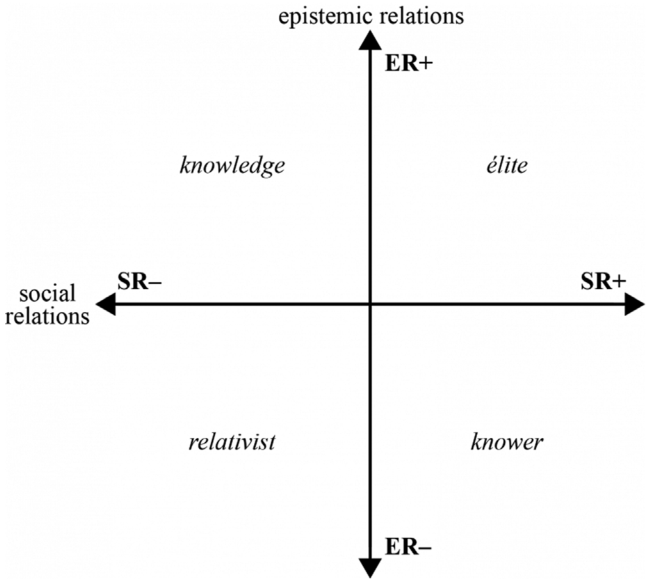

Figure 7.2 The specialization plane (Maton, 2014, p. 30)

The scientists offering the argument of the impossibility of science being colonizing because it is 'objective' are 'knower-blind'. Whilst the students demanding Newton's Laws be dropped are 'knowledge-blind'. The terms knower-blind and knowledge-blind are discussed in detail later. However, all social practices have both epistemic relations and social relations in operation regardless of what is valorized in the particular field. Put another way, decoloniality is both a knowledge problem and a knower problem but one has to begin with the structure of the field itself to determine the most appropriate starting point.

Knowledge-blindness

Our task here is not to revisit the entire argument for the existence of knowledge-blindness, but simply to reflect on the key points, so that by contrast we can show that knower-blindness may be as significant in the natural sciences.

In *Knowledge and Knowers*, Maton writes:

> Never has knowledge been viewed as so crucial to the nature of society. Yet, *understanding knowledge* is not viewed as crucial to *understanding*

> *society*. For what unites accounts of social change is not only their emphasis on the centrality of knowledge but also their lack of a theory of knowledge. Knowledge is described as a defining feature of modern societies, but what that knowledge is, its form and its effects, are not part of the analysis.
>
> (Maton, 2014, p. 1, original emphases)

This critique is primarily aimed at sociological approaches to education research. As Alexander argued, much education literature is mired in an 'epistemological dilemma' created by a false dichotomy between positivist absolutism and constructivist relativism (Alexander, 1995). That is, knowledge is either understood as 'decontextualised, value-free, detached and certain or as socially constructed within cultural and historical conditions in ways that reflect vested social interests' (Maton, 2014, p. 2).

As the twentieth century proceeded it became increasingly clear in some fields in the humanities and social sciences that one's social position had a significant impact on how one engaged with information and constructed knowledge. Positivist absolutism was anathema and in this false dichotomy the only other option was to follow constructivist relativism, which holds that there is nothing real beyond the mental construction (Alexander, 1995). In this paradigm, everyone is a valid knower. Knowledge itself disappears from view and power relations become all important. The mark of being 'educated' is no longer what one knows but 'knowing' in the way that is deemed to be acceptable by those in power in education.

Specialization offers us a path out of this impasse. The false dichotomy is replaced by two orthogonal, and therefore independent, variables. In revealing the dynamic interplay between epistemic relations and social relations both the knowledge and the knower in any field come into view. In a knower-code field, the detail of what is taught is de-emphasized and teaching the student how to interact with the information in such a way as to be seen as a legitimate knower is emphasized, described as developing the appropriate gaze (Maton, 2014). Here choosing texts and authors which speak more directly to the experience of the students may be a reasonable quest. Indeed, the recognition of the ways in which Western modernity has profoundly shaped the very way in which study of the humanities and social sciences is conducted is necessarily a part of the decolonial conversation (Heleta, 2016). Nonetheless, our quest for an education that is appropriate for twenty-first-century South Africa cannot eliminate the impact of Western civilization (Mbembe, 2016). Rather we need to look at the elements which are simply taken for granted in Western modernity. One example is the Western presumption of the primacy of the individual versus the African cultural concept of ubuntu.

In a knower code then, we must examine what is taught. The development of a truly decolonial curriculum is likely to require changing the texts and sources used. It will also require an iterative method to critique the use of concepts and scaffold ideas which are themselves bound to Western civilization. Whilst the former can be achieved relatively quickly, the latter will take years as academics themselves begin to find new ways of exploring and expressing these knowledge areas (Mbembe, 2016). Indeed, the task of decolonial education in a knower code is fundamentally about the development of culturally embedded knowledge practices.

The challenge is a little different in a knowledge code. To substitute Western scientific knowledge with indigenous knowledge is not the place to begin. This approach would substantially erode the value of scientific education. To change the foundation would be to erase scientific knowledge and begin from scratch. Again we must acknowledge here that the modern/colonial conception of knowledge (Maldonado-Torres, 2016) is congruent with, and indistinguishable from, the scientific conception of knowledge.

To present indigenous knowledge systems as science is problematic. This is not because the knowledge itself is suspect; indeed there may be a great deal of very useful information held in these systems. However, what makes scientific knowledge 'scientific' is the method used to verify claims to knowledge, as it is upon the basis of the method that the knowledge claim is made. In order to bring in traditional knowledge systems we have to ask about the manner in which this knowledge has come to be known. If one considers acupuncture as a traditional knowledge system, the knowledge held in the system is powerful and can provide a viable method of healing. However, the language used to communicate what is happening is descriptive, rather than explanatory. Thus whilst the knowledge within acupuncture can be used to good effect it does not have a scientific basis. This does not make acupuncture inherently less valuable; it just means that its inclusion in a science curriculum may create confusion. However, ultimately we will need to find a way to work with different knowledge systems in our education system. That is to say, we need to be very careful about blurring the lines too quickly. It is not our purpose in this chapter to make any move towards disrupting the boundaries of science education. That may well be necessary in time but there is preparation to be done first.

As we have argued elsewhere, we have to find a way of examining what is at stake in science education (Adendorff and Blackie, 2020). Is there a need to decolonize the project of science education even within the narrow confines of its current conception? We argue here that there is such a need. There are doubtless many routes towards a decolonial science curriculum, and we are not claiming that we have arrived, but one has to begin somewhere. Our proposition is that where the knower code fields may have been knowledge-blind, there may be an equivalent 'knower-blindness' in knowledge code fields. Thus our starting point is to argue for the importance of making the knower visible in science and in science education. This focus on knower-blindness opens the door to making visible the coloniality of power and coloniality of being (Maldonado-Torres, 2016), which are unconsciously operational in science.

Knower-blindness

Let us return to the false dichotomy where knowledge is either understood as 'decontextualised, value-free, detached and certain or as socially constructed within cultural and historical conditions in ways that reflect vested social interests' (Maton, 2014, p. 2). In the light of this erroneous juxtaposition it is no wonder that many scientists simply dismiss any calls for decoloniality. Many natural scientists will stand firmly in the value-free zone and presume their educative efforts will follow suit. In fairness, we should perhaps add a little nuance. Most scientists would happily accept decontextualized, value-free and detached knowledge, but would not agree to absolute certainty. We know that what we teach is the best current version of our understanding; many scientists would replace certainty with reliability.

The real power of scientific knowledge is that it is transferable across cultures. Newton's Laws accurately predict the movement of large objects regardless of whether the interaction is observed in Greenland or Argentina. The social standing, political leaning or religious affiliation of the person carrying out the scientific experiment is irrelevant. Whilst scientific knowledge is entirely transferable and acultural, neither the scientific project nor science education is in fact socially neutral. The person of the scientist, shaped by their life experience, will deeply impact their approach to their own projects and their approach to education (Aikenhead, 1996). It is at this level, then, that the project of decoloniality can begin.

Decoloniality in science education

We have found that it is more helpful to approach decoloniality in our context from an experiential point of view rather than a theoretical one (see Chapter 6, this volume). The reason for this is that many academic scientists have very little basic epistemology.[3] Few have had much exposure to knowledge creation that is not rooted in the scientific method and bound to physical measurement. Thus, they can tend to lack respect for academic research generated outside a positivist or realist paradigm. So, we have found it more productive to use illustrations and personal experience to enable academic scientists to begin to see the importance of the conversation. To this end, we have found that it is much easier for academic scientists to recognize that some students in their classes may experience a sense of not belonging and/or a cultural barrier. One source of such negative experience is the use of real world illustrations which may be beyond the experience of those from a different culture and/or social class.

An example of this could be to illustrate increasing rotational velocity using the change in speed that occurs when an ice skater pulls in their arms during a spin. The image of the ice skater may work well in Europe or North America where ice-skating is a fairly regular winter time activity. In sub-Saharan Africa, only reasonably well-off city dwelling children would have had any experience of going to an ice-rink. The middle-class students may be able to make the imaginative leap or have the social confidence to know that the incapacity to make the mental leap is not essential to the topic in hand. A student from a more rural, working-class setting, in struggling to understand the illustration, may not immediately recognize that it is not important to the concept. More significantly, if the student feels out of their depth socially, they are far less likely to admit the lack of understanding. The net result is alienation: a feeling of not belonging experienced because the lecturer, in an attempt to make a concept more accessible, inadvertently used an illustration without considering whether it was actually experientially accessible to everyone in the class.

The simplest start towards decoloniality is an awareness that even though the concepts we teach do not immediately appear to be culturally bound, we do nonetheless teach in and through a cultural paradigm. In the natural sciences, we tend to be blind to social and cultural influence precisely because of the insistence on the objectivity of science. To be a scientist is partly to actively forget that I have been formed in a particular culture as soon as I enter the laboratory, and this mentality gets transferred to lecture theaters. Knower-blindness is not just an accident of the system, it is actively endorsed.

Once the academic scientist has begun to recognize that we bring cultural baggage into our lecture theatres and laboratories, a major source of resistance to the concept of decoloniality has been overcome. The acknowledgement of the cultural baggage brings the coloniality of power into view (Maldonado-Torres, 2016). Here the scientist may begin to recognize that their way of being in the world will impact their interaction with their students. This is the equivalent of Boas recognizing that sound blindness is a real phenomenon. This is an important and necessary first step, but in itself is insufficient for the overall project.

The second, deeper level requires a recognition that social relations do require some attention in science education. This level will ultimately call forth the recognition of the coloniality of being (Maldonado-Torres, 2016) but will require deep engagement to develop new ways of being. Once again, the project of forming scientists is typically located in a knowledge code (relatively strong epistemic relations and relatively weak social relations). Note though, 'relatively weak' social relations do not mean that these relations are absent. The question, then, is how we develop a model of science education that takes into account the human person without eroding the strength of epistemic relations. Here we need to remember the power of Specialization, which allows for independent variation of epistemic relations and social relations in direct contrast to the false dichotomy, which would require sacrificing the power of science knowledge to the service of enculturation (see earlier sections). That is to say we can strengthen social relations without necessarily eroding epistemic relations.

We turn now to the work of Lonergan. We acknowledge that some may well reject using the work of yet another dead white man to help towards the project of decoloniality, but he provides a model which allows us to bring the social relations into view whilst holding true to the essence of robust conceptual understanding which underpins the stronger epistemic relations of the sciences.

Lonergan

Lonergan's project was to understand what it means to understand (Lonergan, 1992). In his method he drew on mathematics, common sense and other divergent knowledge areas precisely because he wanted an explanation that could cover any experience which we would recognize as understanding. Lonergan's desire was to make visible to process of understanding such that it would help any person become a more conscious, reflective and engaged adult, regardless of their chosen sphere.

It is important recognize that the canon of science, which includes reproducibility and cross-cultural transfer, does come with a universalizing claim to 'truth'. Although 'truth' must be understood to mean that which the community has deemed to be the best description of reality we have yet to produce, this may feel hegemonic and brutish to those who work within some knower codes. Nonetheless, we hope that it will be received with a generosity of spirit which will be able to recognize the essence we must preserve if science is to retain its inherent strength and trustworthiness.

Further to the scientific claim to 'truth' being underpinned by the recognition that our current theories are the best yet, new data may arise that will require rethinking and a Kuhnian paradigm shift (Kuhn, 2012). Not all scientific knowledge is of equal rigour and some theories underpin a far larger range of experimental findings than others. We are unlikely to completely rethink evolution or atomic theory, but some of the assumptions that have been made have indeed been reconfigured over time in the light of new discoveries.

The point of making this explicit here is to say that within science there is an established and accepted canon of the necessary foundations of the scientific disciplines. For example, it would be highly peculiar to find an undergraduate chemistry curriculum that failed to cover the Periodic Table or a biology curriculum that failed to cover the classification of organisms. This is precisely what is meant by having stronger epistemic relations. The 'what' that is 'known' matters. Thus, the model of education and decoloniality we employ in our own contexts must take this into account. Once again, it is not at clear at this point in time that one can decouple science from the coloniality of knowledge (Maldonado-Torres, 2016).

Lonergan's model of understanding gives us four steps (Lonergan, 1992). His goal is not simply for me to understand but for me to know that I understand. To achieve this I will need:

> *Experience*, which comprises the learning experience including lectures, tutorials, textbooks, etc., and any prior experience which will influence the way in which I interact with my learning environment. The latter will include cultural considerations, language, and any prior learning.
>
> *Insight*, which is the beautiful 'aha' moment where the fragments of experience click into place and something is understood.
>
> *Judgement*, which requires reflection. Is my insight correct? That is, is my insight in line with that which I am being taught? It is at this point where we must insist in science that there is 'correct understanding' and that correct understanding means in line with current understanding held by the scientific community, rather than claiming an absolute truth.
>
> *Decision making*, which is based on my judgement of whether my understanding is correct, partially correct or incorrect, leading to some action being required. The decision making step is taken to ascertain the appropriate action.

The first step, *experience*, requires engagement with community – as humans we learn from one another and our experience is framed by prior learning. Even if no other person is physically present, a textbook is still written by another human being. The second step, *insight*, is individual. The moment of insight is interior to the mind of one person, even if this happens in the presence of another who has helped place the pieces so that they can cohere. The third step, *judgement*, will again require engagement with the community. It is impossible to ascertain correct understanding without checking what the community understands. Again, this may simply be re-reading a paragraph in a text book but it is still a communal activity. Finally, *decision making* is individual but it will have a communal effect. My decisions will impact my world in some way.

In the context of science education then we can do very little about the structure of the knowledge itself. Nonetheless, the conscious engagement with others to verify the knowledge begins to make visible both 'being' and 'power'. Many academic scientists, ourselves included, have happily sent students on their way once they get to that beautiful aha moment, presuming that they have understood correctly simply because something has 'clicked'. We fail to ask the students what they think they understand. We take the experience of insight at face value and presume that it is correct understanding. However just because there is some experience of connection and sense making does not mean that there is correct understanding (Lonergan, 1992). The scientific project itself is never a lone activity regardless of the caricature of the mad professor or the individualist way in which the scientific method is sometimes presented (McComas, 1996). The judgement and decision making parts of the process are an inherent part of the scientific method and require engagement with the community. The fact that we fail to make that explicit to students is a significant failure in the educational project. This engagement with the community will impact the way in which the student understands their position in the world and therefore will certainly impact their being, and in time will have an influence on how power is distributed.

In terms of the decolonial project, we argued in the opening section of this chapter that one area of Western modernity which is highly problematic is the primacy of the notion of the autonomous individual. The vagaries of individual preferences are to be followed without any cognizance of impact on the community. Lonergan's model immediately highlights two important areas where culture and community can be directly engaged. The first is in the simple recognition of the significance of the diversity of lived experiences within the student cohort. As described earlier, any real life examples must be examples which are truly accessible to all students or the students should be asked to offer their own examples which illustrate the concept. We have found that is a powerful aid to conceptual gain in itself as examples are then shared – this widens the repertoire of the lecturer and all the students. Furthermore, misconceptions can be revealed as poor examples emerge and afford a useful teaching opportunity. At a deeper level, there can be a real validation of the diversity of experience, which helps mitigate alienation. Importantly, this process is also illuminating for the lecturer.

They learn a good deal about the students sitting in front of them. This personal interaction ultimately has the potential to shift everyone in the lecture theatre a little (or a lot).

Second, the recognition that both judgement and decision making are activities which require engagement with community shifts the educative paradigm. This is no longer pouring knowledge into an empty vessel to create a 'mini-me'. It is a deeply empowering experience which will shape the way the student (and ultimately the scientist) engages with the world. We are no longer teaching science then to fill the 'science' bucket in the brain, what we are actually doing is formative. Importantly, the emphasis on communal engagement means that we are immediately diverging from one of the most toxic and problematic aspects of Western modernity – the primacy of the idea of the autonomous individual where my individual 'freedom' trumps any social responsibility. If science education is focused only on conceptual understanding, we will continue, unconsciously and blindly, to foster this mindset. Shifting to the recognition that engagement with the scientific community is an indispensable part of the process makes the myth of the autonomous individual much harder to sustain.

Conclusion

The project of decoloniality within the natural sciences is substantially different from that in other knowledge areas. The main reason for this is the inextricable link between a colonial construction of knowledge and science. However, there is real space to reveal the coloniality of power and coloniality of being to which science is almost entirely blind. This chapter is written primarily for scientists using the tools of social science to show that we have a credible starting point. In this chapter we do not claim to have clarity on what decolonial science education will look like. It will take a substantial culture shift within natural science itself to achieve that. What we propose here is an entry point.

We have argued that one major issue which needs to be addressed in the decolonial project in science results from the 'knower-blindness' and the concept of the autonomous individual. Knower-blindness results in a conflation of the objectivity of science and the objectivity of the scientist, which hitherto has been at the heart of Western modernity. This means that the scientist is presumed to be acting objectively and so any critiques of the uses of science are easily fobbed off. Decolonial science education means that we pay attention to this conflation by introducing an awareness of the variation of experience in the student body, which necessarily shifts the non-reflexive tendency to universalize the experience of the lecturer.

The primacy of the individual results in the perpetuation of the valorization of the rights of the individual over any consideration of what it is best for society. Here embedding a process of reflection in a model which requires us to pay attention to the presence of the scientific community is at least an entry into eroding the lack of awareness of the significance of others. We hope we have shown that through the dual lens of Legitimation Code Theory and Lonergan's model of understanding, there is a way to take cognizance of the importance of the human person in their context and facilitate scientific dialogue in such a way that society itself can be transformed in a way that does not inherently erode the knowledge which must be the basis of any credible science education.

Notes

1 The distinction between coloniality and colonization is discussed at length in Chapter 4 of this volume. The distinction is not central to the argument in this chapter.
2 The relationship of the *epistemic plane* to the Specialization dimension of LCT is discussed in Chapter 6 of this volume.
3 This is perhaps cause to take seriously the concept of pluriversalism discussed in Chapter 5 of this volume.

References

Adendorff, H. and Blackie, M. A. (2020) 'Decolonizing the science curriculum: When good intentions are not enough'. In C. Winberg, S. McKenna and K. Wilmot (Eds.), *Building knowledge in higher education: Enhancing teaching and learning with Legitimation Code Theory* (pp. 237–254). London: Routledge.

Aikenhead, G. S. (1996) 'Science education: Border crossing into the subculture of science', *Studies in Science Education*, *27*(1), 1–52.

Alexander, J. C. (1995) *Fin de siècle social theory: Relativism, reduction, and the problem of reason*. London: Verso.

Boas, F. (1889) 'On alternating sounds', *American Anthropologist*, *2*(1), 47–54.

Burchfield, J. D. (1975) 'Radioactivity and the age of the Earth'. In *Lord Kelvin and the age of the earth* (pp. 163–211). London: Macmillan Education UK.

Costandius, E., Blackie, M., Leibowitz, B., Nell, I., Malgas, R., Rosochacki, S. O. and Young, G. (2015) 'Stumbling over the first hurdle? Exploring notions of critical citizenship'. In M. Davies and R. Barnett (Eds.), *The Palgrave handbook of critical thinking in higher education* (pp. 545–558). New York: Palgrave Macmillan US.

Darwin, C. (1859) *On the origin of species by means of natural selection or the preservation of favoured races in the struggle for life*. London: International Book Company.

Engelbrecht, J., Harding, A. and Potgieter, M. (2005) 'Undergraduate students' performance and confidence in procedural and conceptual mathematics', *International Journal of Mathematical Education in Science and Technology*, *36*(7), 701–712.

Fabbrizzi, L. (2008) 'Communicating about matter with symbols: Evolving from alchemy to chemistry', *Journal of Chemical Education*, *85*(10), 1501–1511.

Goodman, S. N., Fanelli, D. and Ioannidis, J. P. A. (2016) 'What does research reproducibility mean?', *Science Translational Medicine*, *8*(341), 1–12.

Heleta, S. (2016) 'Decolonisation of higher education: Dismantling epistemic violence and Eurocentrism in South Africa', *Transformation in Higher Education*, *1*(1), 1–8.

Joly, J. (1900) 'IV – The geological age of the earth', *Geological Magazine*, *7*(5), 220–225.

Kuhn, T. S. (1977 [2003]) 'Objectivity, value judgment, and theory choice'. In A. Bird and J. Ladyman (Eds.), *Arguing about science* (pp. 74–86). London: Routledge.

Kuhn, T. S. (2012) *The structure of scientific revolutions*. Chicago, IL: University of Chicago Press.

Lonergan, B. (1992) *Insight: A study of human understanding*. Vol. 3. Toronto: University of Toronto Press.

Lyell, C. (1853) *Principles of geology: Or the modern changes of the earth and its inhabitants considered as illustrative of geology*. London: John Murray Publishers.

Macdougall, J. D. (2009) *Nature's clocks: How scientists measure the age of almost everything*. Berkeley: University of California Press.

Maldonado-Torres, N. (2016) *Outline of ten theses on coloniality and decoloniality*. Frantz Fanon Foundation.

Maton, K. (2014) *Knowledge and knowers: Towards a realist sociology of education*. London: Routledge.

Mbembe, A. J. (2016) 'Decolonizing the university: New directions', *Arts and Humanities in Higher Education*, *15*(1), 29–45.

McComas, W. F. (1996) 'Ten myths of science: Reexamining what we think we know about the nature of science', *School Science and Mathematics*, *96*(1), 10–16.

Potgieter, M. and Davidowitz, B. (2011) 'Preparedness for tertiary chemistry: Multiple applications of the Chemistry Competence Test for diagnostic and prediction purposes', *Chemistry Education Research and Practice*, *12*(2), 193–204.

Roepstorff, A., Niewöhner, J. and Beck, S. (2010) 'Enculturing brains through patterned practices', *Neural Networks*, *23*(8–9), 1051–1059.