High Educ (2015) 70:409–416
DOI 10.1007/s10734-014-9842-x

The future of knowledge and skills in science and technology higher education

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Published online: 17 December 2014

Abstract This paper begins from the assumption that *knowledge specialisation and differentiation* will continue to increase, and that these features of contemporary STEM knowledge will increasingly pose questions which science and engineering education must address. Two typical responses are outlined. The first response, the default position, has come to be known as *traditionalism*, a minimal response that attempts to shore up a high-selectivity, low curriculum change elite template by means of repair services, which is where Academic Development in the universities began. The second response, a '*progressive*' one reacting to traditionalism, strove to put the learner and the act of learning in the spotlight, inadvertently thereby foregrounding skills and backgrounding the knowledge to be taught and learnt. The paper goes on to discuss de-differentiating features of this second response and argues that this will over time undermine the capacity of the university to deal effectively with rapidly evolving specialisation and differentiation. The paper concludes by considering a third way to address the issue.

Keywords Specialisation · Differentiation · Knowledge · Skills · Know that · Know how

There is an undercurrent of confident futuristic prognostication in much contemporary popular writing about education and in the projections of some scholars too. Education, it seems, is 'out of step' with the times in general and the labour market in particular. Universities are regularly lambasted for not providing the skills future workers in the 'knowledge economy' will need (see Case 2011 for a discussion regarding engineering) and skills which, ironically, are often at the same time said to be changing rapidly. Solutions appear to many soothsayers to be blindingly obvious. 'Lifelong' learning is for some the remedy (see for example Knapper and Cropley 2000), although the prospect of a

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society of Sisyphean learners comes close to Orwell's dystopia. For others, the newer technologies provide the answer (Bates and Poole 2003). For yet others, learning must be liberated from the dead hand of outmoded disciplines and those that profess them. More audaciously, we are told that traditional forms of research no longer produce what we need, and we are ushering in a new era of transdisciplinary, trans-institutional research called 'mode 2', to distance it from its discredited 'mode 1' forebear (Gibbons et al. 1994).

Some years ago, in response to a commission from the *Beyond Current Horizon Programme* headed by Carey Jewitt, Michael Young and I resolved to venture into the cauldron of futurology, to give our account of what was happening from a sociology of knowledge perspective (Young and Muller 2010). The result was an exercise in 'futures thinking' of a special kind. In that paper, we tried to project a developmental trajectory from the past into the future, from an ideal type we called 'Future 1' to another called 'Future 3'. The aim of this present paper is to elaborate the argument of that paper in the context of science, technology, engineering and maths (STEM) in higher education, in so doing examining their implications for science and engineering education now and in the near future.

There are two *basic departure points* in the original paper of significance for the present one. First, there is no doubt we are living in a time of increasing *specialisation* of knowledge in the STEM domain, driven equally by new discoveries and inventions, new technological challenges and new elaborations in the division of labour—that is, new kinds of jobs and the obsolescence of older ones (Brown and Lauder 1996). In our educational lifetime, the increasing specialisation of knowledge is a defining condition that educators especially in concept-rich domains like STEM simply have to adapt to. Increasing specialisation entails an ever-increasing addition of new knowledge and with it, an ever-increasing raising of the cognitive demand bar at each level of the educational ladder. All science and engineering lecturers know this means having to deal with a curriculum that is already bursting at the seams, and they have to avoid solving the problem the 'easy way'. This 'easy way' is to increase the pacing (compressing and speeding up) of curriculum material, which in turn favours students from privileged backgrounds because they are better equipped by virtue of being educated in cognitively rich environments by better qualified teachers to respond to the increased volume of novel material. The position taken here is that we are ethically bound to search for formats of learning that help us to expand opportunities for students from less privileged educational backgrounds, not shut them down. In educational terms, however, this is only where the debate begins and does not yet indicate how this should be done.

The second departure point is the ineluctability of the *differentiatedness* of knowledge. Different knowledges (disciplines and their curricular carriers) have different epistemic and social properties. This has entailments for differential arrangements for doing research; differential forms of collegiality; differential forms of curriculum coherence; and so on (Muller 2009). Complex high-specialisation professional faculties like Health Sciences, Engineering and Architecture are a dynamic conglomeration of different socio-epistemic communities each with their distinct cognitive and cultural styles (Becher 1994; Becher and Trowler 2001), whose differences have to be managed if they are not to bump ceaselessly into one another.

What the scenarios paper does in addition is sketch three notional scenarios or 'futures', based on fundamentally different ways of dealing with these above two departure points. Scenarios 1 and 2 are plain enough. The first is what I will call *traditionalism*, a position based on what Young and Muller (2010) called an 'under-socialised' concept of knowledge; the second is *progressivism*, a reaction to traditionalism, which ends up, we argue, with an 'over-socialised' concept of knowledge. These scenarios clearly display similarities as well as differences across the terrains of schooling and higher education.

Scenario-sketching of this kind can easily lead to envisaging a straightforward progression path from scenario 1 moving on to scenario 2 and eventually to scenario 3. Such an impression of inevitability would be illusory. Scenario 1 was designed as a civilising device for the youth of the elite, where the content of the curriculum was regarded as relatively fixed and of primary importance. It fell victim to its own internal shortcomings, principally, for the purposes of this paper, that it could cope neither with a massifying, diversifying system nor with the exponential growth of new knowledge after the 1950s. Scenario 2 emerged as a liberatory alternative emphasising the creative activity of lecturers and students and, in trying to deal with the rapid growth of innovation and diversity, foregrounded activity and backgrounded what was to be learnt—the increasingly specialising knowledge base. Science and engineering higher education followed an analogous pattern.

Scenario 2 is the one that is in place today, increasingly put under pressure by blind spots of its own, and will form the main focus of this paper. Nevertheless, it must be stressed that each scenario has, or had, a rational kernel to it. Traditionalism was lost sight of in the enthusiasms of scenario 2, and we must take care that we do not do likewise with scenario 2 at the same time as we retrieve what is good in scenario 1, casting them both in new terms under changing conditions in what we call scenario 3, our social realist alternative.

The argument to be made in this paper is that it is important to take each of these scenarios seriously. Traditionalism in the sphere of STEM has meant an approach to knowledge as either a form of rationalism which elevates theory and hence the theoretical disciplines, or a form of empiricism which elevates propositional knowledge ('facts'), usually both (Muller 2014). This is no accident. Both Descartes (rationalism) and Bacon (empiricism) were necessary for scientific and technological take-off in the seventeenth century (Gaukroger 2006). They ground the very idea of knowledge progress and hence of the roots of specialisation. They are consequently the bedrock of science and technology's self-image. In this sense, in science and engineering faculties, they will always be with us, at least in the research domain. Pedagogically, though, they can lead to a curiously undynamic view of the curriculum and of teaching and learning.

Traditionalism fosters elitism because, as it expands to accommodate growing demand without fundamental attention to its form and changing social base, it replicates enduring patterns of social privilege. This is so for the reason already alluded to: as the curriculum copes with specialisation pressures by upping the pace of transmission and increasing demand levels, it is the already-prepared students who cope best. The enduring symptom of traditionalism's blind spot is high levels of student dropout and repetition. This had led to successive models of scenario 2 'first aid' which have had some effect but have not solved the problem. Most recently, there have been a series of technological/technocratic means for addressing the problem, MOOCs being just the most recent, but these often just displace the problem, by laying it at the door of students; after all, one does not 'drop out' of an online course so much as de-register for lack of interest. What they share with traditionalism is that they all take for granted the fixity of the knowledge horizon and locate the problem 'out there' with the educational participants, or the technologies that mediate them.

It is largely to tackle traditionalism's creaking view of learning and teaching that led Academic Development[1] , at least in South Africa, to embrace the second scenario during

[1] Academic Development, also referred to in the literature as Education Development, is concerned with staff development, curriculum development and, in South Africa, student development.

the period of its growth and expansion in the 1960s, 1970s and 1980s (see Scott 2009 for an historical account), often as an article of faith or badge of professional identity, and, until recently, rather uncritically. This has begun to change (see Case 2011; Shay 2012; Luckett 2009).

Progressivism has a number of things going for it. Its founding insight, rooted in a constructivism which opposes rationalism and empiricism equally, is that however apparently fixed the knowledge horizon might appear, it is always the product of human activity and its history. This shift of view, to the *activity*, was initially dramatically liberating, both politically and epistemically (Young and Muller 2007). Because of its refusal to take social and educational hierarchies as given and unchangeable, progressivism in South Africa was initially aligned with the democratic movements of the 1960s and 1970s and continues to be claimed for progressivism today.

Constructivism as a theoretical movement underlying pedagogic progressivism (Moore 2012) was a serious attempt to establish a sociological basis to debates about the curriculum. It has shed considerable light on the processes of pedagogy and learning (see for example Biggs and Tang 2007) just as its counterparts in the sociology of science has shed light on the processes of scientific discovery (see for example Pickering 1992). However, in its attempt to socialise knowledge, the curriculum and pedagogy, it tended to slip into a relativism that threw the baby (knowledge, truth, objectivity) out with the bathwater (a static and ahistorical view of knowledge). Because knowledge is originally constructed is no reason to doubt that some of it, at least, is worthwhile, true and objective, or that a spirit of truthfulness is something to be prized (Williams 2010).

In STEM, the case for the constructedness of reality and truth must have been hard to maintain in the face of hard-nosed scepticism from the scientists and an equally hard-nosed pragmatism from the engineers. But its corollary that things of the world could be changed by righteous human endeavour, stuck, probably striking some kind of chord with the 'can do' engineers. If the verities of education were constructed, then they could be changed. The lecturer and the student, the two founts of activity, became the focus of the scholarly Academic Development gaze, still overwhelmingly the case today (Case 2013). If the attempt to make a difference failed, then it must have been, it must be, for want of epistemic fortitude and sociopolitical will. Consequently, there is all too often more than a whiff of moralism in some contemporary Academic Development writing.

This focus on the activity (or on 'practice') has, probably inadvertently, tended to draw a veil over the knowledge base on which successful action depends, and hence most crucially, over the differential curriculum requirements of specialised knowledge. In other words, the focus on the activity of teaching (and learning) mostly leaves out of view the different kinds of knowledgeability on which that teaching rests, which is sometimes even seen as a virtue (Dall'Alba and Barnacle 2007). Hence, almost against its initial liberating intents, progressivism (scenario 2) has tended to get stuck with an over-socialised and undifferentiated conception of knowledge as activity. To put that another way: scenario 2, especially in the Anglo-American tradition, has ended up with a notion of 'practice' as skill, competence or punctual performance, a 'thin' version rather than the more capacious sense of educational 'practice' signalled by the German term 'kompetenz', which is a 'thick' notion incorporating formal knowledge, past abilities and moral character (Winch 2010; Boehlinger 2007).

Scenario 1 and scenario 2 are each movements of their time. Because they each describe a partial truth of the STEM educational situation, they each display a certain incorrigibility. This means that, amongst their core constituencies, they continue to function as the 'one and only' account, the 'one best system' (Tyak 1974), in opposition to others which then become false pretenders. As a consequence, they have become embroiled in a polarised debate between their respective positions. We had the Culture Wars of the 1970s, the Science Wars of the 1980s, each describing a certain fierce engagement at the buffer zone between them. A low intensity Pedagogical War has flared up intermittently, for example in Engineering and Medicine, between the proponents and opponents of 'problem-based learning' (Case 2011; Hartman 2014). Since the position of each suppresses important aspects of the other, this has led in education to a fruitless oscillation from one to the other and back again. In the universities and in Academic Development in particular, this has led to the educational progressives hunkering down and chipping away at the perceived certainties of their academic colleagues in the science and technology departments and faculties, without much signal success except in the small-scale research and intervention studies that fill the research publications.

Scenario 3 is the name Michael Young and I have given to the space that explores what it means to move the debate forward by combining the positive features of each and trying to avoid their worst features. However, we are not presuming that one can simply survey strengths and weaknesses and make a judicious selection. As indicated above, the two scenarios are thoroughly socio-historical phenomena and they leave behind specific historical sediments and path dependencies. In the case of science and engineering education, this has meant a residual scenario 1 orientation in the mainstream STEM departments and a spirited scenario 2 orientation in response, or opposition, amongst the Academic Development practitioners, with many variants in between. Academic Development generally, and in STEM, leans thus to a basic scenario 2 orientation. One way to move forward, the analysis above suggests, is to confront the tendencies towards de-specialisation and de-differentiation inherent in the scenario, and thereby to at least foreground the tendential limitations of the position.

I will list some potential de-differentiating features of scenario 2, but will explore only one briefly in the remainder of this paper. Most if not all of them arise as over-extensions of the basic postulate of scenario 2, namely, its fundamental activity or *practice orientation*. As I said above, this orientation has had positive effects because it socialises the basically ahistorical orientation of scenario 1, and it liberates by emphasising the moment of dynamism and transformation immanent in the very notion of action. At the same time, the practice orientation has all too often led to a valorisation of:

- Agent-centred experience at the expense of specialised kinds of knowledge;
- Learner differences at the expense of knowledge differences;
- A generic pedagogy, say outcomes-based or problem-based learning, instead of considering pedagogies as specific to kinds of knowledge;
- Skills at the expense of knowledge (see also Muller and Young 2014).

There is something powerfully intuitive about this notion of skills in science and engineering education. It points directly to competencies that successful students must be able to display and to what unsuccessful students cannot do. Yet how are these to be stipulated in non-circular terms? How do we say what the student must be able to do without stating the obvious—'the student must be able to do a successful design project'? Yet what this seemingly 'obvious' point hides from view is the fact that 'doing a design project' entails a dramatically different curriculum and pedagogical arrangement, an 'integrated' code rather than the traditional 'collection' code they will have been accustomed to in their courses up to that point and which requires quite different 'recognition rules' in order to meet the new evaluation expectations (Kotta 2011).

The problem of skills stipulation in STEM as elsewhere in education is that it is very hard to describe skills (or 'techniques', or 'outcomes' and other 'can do' surrogates) in other than general or generic terms, which right at the outset obscures the speciality and differentiation of the knowledgeable practice in question (Winch 2014). In things like the fourth-year design project in engineering programmes in South Africa, for example, it is manifestly a 'can do' kind of thing we are talking about. But it is a different 'can do' than the one expected and required by the traditional courses—or by the 'design project' in Architecture, for example (Carter 2014). Which 'can do' or 'know how' employers are referring to when they say that students 'can't do' stuff is thus far from obvious. What kind of knowledge is 'know how', and how might it vary?

Winch (2013) has suggested that every area to be educationally mastered in the curriculum can be described in terms of:

- *Know that*, or propositional knowledge;
- *Know how*, or procedural knowledge.

More to the point here, there are three different kinds of 'know how' knowledge. The first kind is what is called *inferential know how*—knowing how the conceptual knowledge (the 'know that') learnt in the regular courses of Chemistry and Chemical Engineering, for example, hangs together, and how to negotiate the epistemic joints that link the various knowledge 'bits' together. Already between these two subjects—Chemistry and Chemical Engineering—the internal inferential relations, the internal conceptual logic, will differ, because of their different epistemic purposes, a potentially confusing difference which must be mastered via their respective recognition rules (Smit 2012).

The second kind is *procedural know how*[2], which is not really a satisfactory name because it sounds of somehow lesser status ('that's just procedural knowledge') than its epistemic twin. In fact, it points to a more risky and uncertain kind of knowledge where the neophyte learns how to find out new things, find out what warrants and tests work under what circumstances, what the tolerances and limits are in real situations, forming new judgments that lead to solutions that work in the world.

The third kind of know how Winch discusses is *personal know how*, which is the idiosyncratic knowledge accumulated through diverse experiences in the process of actually 'doing it'. Most of this would not be codified, unless the practitioner takes the trouble to publish it in a trade or academic journal, or in more important cases, via a patent or registered software (Foray and Steinmueller 2002).

Added to this, Winch distinguishes also a range of different more practical 'know hows' that are usually conflated when educators loosely talk about 'skills' or 'practical expertise'. As Winch (2014) says: 'Within the Anglo Saxon countries it is almost a reflex to talk about occupational know-how in terms of skill, as if there were no other kind of practical ability worthy of consideration. This tendency has had deeply damaging effects on the ways in which professional and vocational curricula are thought about'. These practical 'know hows' include techniques, skills, transversal abilities, 'project management' (what Winch means here is something like the multilevel, multi-'skill' demands of a design project) and occupational capacity. These are all different and failure to grasp one or more could jeopardise competence in the whole.

[2] Confusingly, 'procedural knowledge' is usually the name given to inferential knowledge that is coded into an algorithm, a piece of software, a routine. What it means in this sense is a set of relations that have been tested so often in so many situations that they can be taken as a reliable shortcut—until they no longer work. Following Winch, I am using it in a broader sense here.

The first point about these different knowledges is that they are *cumulative,* in three senses. First, the student must have reasonable mastery of the *know that* (the conceptual content) before she can begin to grasp how the *know how* works (Bengson and Moffett 2007). Secondly, the student must be brought to grasp the inferences and the inferential relations before she will be able to venture out into uncertain territory with the *procedural know how* with any confidence. Thirdly, the various know hows are themselves nested—they also ascend epistemically (Winch 2013), which is to say, they also have features of greater or lesser complexity which must be correctly sequenced in a coherent curriculum.

The second point, already stressed above, is that these various parts of the curriculum are *epistemically different*: they require different kinds of stipulation, they entail different recognition and realisation rules, they have different evaluation criteria and they entail different pedagogic relations, as Kotta (2011) showed. The main point is that simply calling them 'skills' does not help us describe what they are, or understand what goes wrong when students do not 'get' them, or cannot 'do' them (see also Allais 2014).

This paper advances the following tentative predictions for the future of science and engineering education. The first is that, unless matters change drastically—which they show no sign of doing at present—the diverse knowledges of the STEM disciplines will continue to advance and specialise apace. Demands for access to, and demands for, STEM knowledges and practical know how will also escalate, bringing larger and more diverse constituencies into the universities. This will soon make the viability of a scenario 1 pedagogic arrangement, however, patched and propped up by scenario 2 efforts, unworkable, if it has not done so already. The spotlight will thus come to focus more and more on scenario 2 efforts, which will probably become bolder and more ambitious. In order for these to achieve their aims of a fairer and more just access to knowledge, scenario 2 will have to make more visible the epistemic obstacle course that is the evolving science and engineering curriculum. To do so will require illuminating the differential *internal epistemic and pedagogic architecture* that we require students to negotiate. Which parts do they get with ease? Which parts seem difficult to which kinds of students? Are we making it more difficult for them by arranging things in this way rather than that? Can we illuminate the recognition and realisation rules more clearly? In this way, what Young and I (2010) called scenario 2 will begin to make way for an emergent alternative scenario, for a more robust scenario 3, that is better equipped to negotiate the specialising future.

Acknowledgments This work is based on research supported in part by the National Research Foundation of South Africa (UID 85813). The Grantholder acknowledges that opinions, findings and conclusions or recommendations expressed are those of the author, and that the NRF accepts no liability whatsoever in this regard.

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