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Trends, Issues and Possibilities for an Interdisciplinary STEM Curriculum

Victoria Millar [1]

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Abstract
In the last decade, the term STEM has been increasingly picked up internationally and come to represent a solution to a range of issues. Within education, STEM is being translated as a curriculum organiser that has the possibility of engaging and retaining students and is interdisciplinary and skills focussed. This paper takes the STEM curriculum as its focus and investigates the influences that have resulted in the current interpretation of STEM as well as the epistemological questions, tensions and issues that this curriculum raises. The paper does this through a consideration of previous and current curriculum movements and debates and in doing so raises questions about the underlying assumptions, form and focus that STEM curriculum take before considering some possible future directions.

Keywords Curriculum · Interdisciplinary · Epistemology · STEM

1 Introduction

The term STEM, a collective term for the four fields of Science, Technology, Engineering and Mathematics, has come to prominence internationally over the last 10 to 20 years. Having been increasingly picked up internationally in discussions, policies and positioning papers across a range of sectors including government, industry and education, the term has become prolific. STEM is now used in discussions of economic prosperity, the labour market, research and innovation and education and represents a broad range of purposes and issues (Office of the Chief Scientist 2012; Department of Education 2009; Wong et al.2016).

As the discourse around STEM has grown, there has in many countries been a focus on STEM in schooling, for example in Australia (Office of the Chief Scientist 2012), the USA (National Science and Technology Council 2013) and the UK (The Royal Society Science

✉ Victoria Millar
vmillar@unimelb.edu.au

1 Melbourne Graduate School of Education, University of Melbourne, Parkville, Victoria 3010, Australia

Policy Centre 2014). This paper will take as its major focus the Australian context, although given the many similarities between Australia and the move toward STEM in other countries, international examples from other English speaking countries will also be drawn on.

In relation to education, the term STEM has come to represent more than just a means for talking about the disparate STEM disciplines and instead is seen by many stakeholders as providing a solution to a range of issues and as requiring a particular kind of curriculum structure or pedagogical approach. Governments, curriculum bodies and schools across a wide range of countries have resolutely taken up the idea of STEM and can be seen to be investing in a wide range of STEM initiatives. Yet while the possibilities and potential of STEM have driven this investment, there are also many tensions inherent in the broad umbrella of STEM education and associated implications that have either not been explored or are yet to be fully understood. This paper seeks firstly to investigate the influences that have led to the current interpretation of the school STEM curriculum, its multiple purposes and structural requirements in order to understand what it is attempting to achieve. The paper then explores the epistemological questions and possible issues that arise from implementing such a curriculum by drawing on work from the sociology of education, curriculum theory and previous attempts to implement similar curriculum. In particular, this paper utilises the work of Bernstein (1971, 1996) in considering the structuring of knowledge, curriculum and the sociocultural influences on and of curriculum. The work of Bernstein and others is then used to consider previous attempts to implement curriculum that have a focus on generic skills (for example the Queensland New Basics) as well as interdisciplinarity (for example the Science Technology Society movement). In doing so, the paper will consider the tensions that arise in attempting to reconcile the multiple purposes of a STEM curriculum.

The curriculum has been taken as the focus for this paper as it is a core ‘message system’ of education and reflects ‘what counts’ as valid knowledge at a particular time (Bernstein 1971). Curriculum is also political in that the question of what is valid knowledge will be answered differently and have different consequences for different groups (Wahlstrom 2018) and so curriculum is not a neutral representation of content that is to be taught but instead is a ‘socio-political and cultural process’ (Karseth 2006). An investigation of the STEM curriculum therefore provides a means to explore what is seen to be important by particular societal groups such as industry and educators, the reasons that STEM has become such a large part of the discussion about school science, technology, engineering and mathematics and what it has come to represent to these various invested groups.

In 2013, the curriculum and critical theorist Michael Apple wrote of the ‘collective amnesia’ in education, where previous efforts in the field are often quickly forgotten with the implication being that history is not guiding new approaches and ideas. STEM education sits in an interesting space in that there are aspects of the current move toward a school STEM curriculum that have been seen previously in school curricula. While engineering is a relatively new inclusion in the school curriculum (McDonald 2016), there have over many decades been attempts to implement interdisciplinary science, mathematics and technology curriculum. One example of this is Science-Technology-Society (STS) based curricula (Fensham 2013) that will be discussed later. There have also been pushes for context based learning (Fensham 2009) and curriculum that have more of a focus on skills (Whitty 2010). Yet some of the issues and questions that have arisen from previous attempts to implement these kinds of curricula are not always investigated or acknowledged. Epistemological questions are raised in this paper about the dominant forms of STEM curriculum and how these affect particular societal groups. This paper will also consider issues with implementing a STEM curriculum in schools in light of previous curriculum movements and theories as a way of providing some insight into the complications and possibilities that arise from curriculum deliberations around STEM.

A significant focus of the push toward school STEM internationally has been on the STEM curriculum being interdisciplinary. Interdisciplinarity has different implications for primary and secondary schooling given the way these levels of schooling have been traditionally structured and taught. The traditional role of the subject in secondary schools as a way of employing staff, structuring staff rooms and dividing the curriculum means that the issue of siloing is different to that in primary schools. For the purpose of this paper, secondary schooling will therefore be the main source of discussion.

In order to better understand the way in which the school STEM curriculum has come about, what it is attempting to do and issues with implementation, the work of sociologist of education Basil Bernstein on the 'pedagogic device' (1990; 1996) provides a way to consider educational practices and contexts as well as their underlying structure. It helps us investigate how pedagogic discourse is constructed by looking at the underlying principles and participant groups that are responsible for knowledge production, knowledge recontextualisation and knowledge reproduction.

Bernstein (1990, 1996) identified three hierarchical fields of the pedagogic device: the fields of production, recontextualisation and reproduction. This paper is concerned with the fields of production and recontextualization. It is in the field of knowledge production that new knowledge is produced. This new knowledge is structured through 'distributive rules' that 'regulate the relationships between power, social groups, forms of consciousness and practice' (Bernstein 1996, p. 42). These rules govern what knowledge is considered worthwhile and who should have access to this knowledge. The field of knowledge production typically takes place in universities and other research institutions and is often connected with the disciplines (Millar 2016).

Within the field of recontextualisation, knowledge from the field of production is purposefully chosen and repositioned to become educational knowledge. This is where knowledge is selected from the disciplines and transformed into curriculum. Recontextualising rules regulate the 'what' and 'how' (Maton and Muller, 2007, p. 11) of curriculum. The recontextualising rules 'regulate the formation of specific pedagogic discourse' (Bernstein 1996, p. 43) which 'selects and creates specialised pedagogic subjects through its contexts and contents' (Bernstein 1996, p. 46). Recontextualisation may occur at a range of levels from more local education department offices, to school curriculum committees and by teachers. According to Bernstein (2000), when knowledge is relocated from the field of knowledge production to the field of recontextualisation, this translation is often indirect and is the space in which ideology comes into play. 'The "what" of knowledge recontextualisation is strongly regulated by moral or regulative discourses, that is, the imagined model of the teacher, learner and pedagogic context discursively constructed by the policy actors' (Singh, Thomas & Harris 2013, p. 469). It is here that curriculum developers have the opportunity to include their ideals about the purpose of education and notions of the ideal learner and graduate. It is for this reason that curriculum is not static but rather reflects 'what counts' (Bernstein 1971) as valid knowledge at a particular time and is continuously contested and evolving. The first part of this paper takes up this idea to explore the different groups and influences on school STEM and the various purposes that the term is attempting to deal with both in Australia and internationally. In light of previous curriculum moves and theories, this paper will then take the idea of STEM developed in the first part of the paper to consider some of the implications and issues with recontextualising a STEM curriculum for the classroom.

As will be discussed throughout the paper, one interpretation of the STEM curriculum is an attempt to move beyond the traditional siloed subject teaching of science, technology, engineering and mathematics. In the case of STEM, consideration needs to be made of how expert knowledge is selected from across disciplines and converted into a STEM curriculum. How such a curriculum is then implemented within the school environment and the possible issues that may arise in the process also needs examination.

As a way of considering the various societal groups that are each attempting to control the development of a STEM curriculum, the following sections will look at the main arguments that have led to its rise.

2 The Rise of STEM in Government and Industry Policies and Discussion Papers

The rise of STEM in schooling can be attributed to a range of influences. STEM at the school level is interlinked with views that STEM is important to the economy, to recent debates about skills and about engaging and retaining students in the STEM fields (National Science and Technology Council 2013; The Royal Society Science Policy Centre, 2014; Ministry of Education 2009). This section will look at how the STEM curriculum has been positioned in government and by industry groups as providing a solution to this range of interrelated issues.

In Australia and internationally the rise of 'the knowledge economy' in government discourse and policy papers has seen greater interest and investment in education by governments who want to ensure that they have the educated citizens to take on the knowledge work required for a productive economy (Rizvi & Lingard, 2010). It has been argued that internationally in an era of policy borrowing across nations (Lingard, 2010) education policy increasingly references economic imperatives (Ball, 2008). Within this context, STEM and STEM education have unsurprisingly been identified by many countries as areas of importance to the knowledge economy as shown in the following extracts from Australian government and industry documents:

> Science and innovation are recognised internationally as key for boosting productivity, creating more and better jobs, enhancing competitiveness and growing an economy (Office of the Chief Scientist 2014, p. 7).

> Australia's productivity and competitiveness is under immense pressure. A key way to meet the emerging challenge of developing an economy for the 21s Century is to grow our national skills base – particularly the Science, Technology, Engineering and Mathematics (STEM) skills of our school leavers (Australian Industry Group, 2013 para. 1).

While international policy borrowing takes different forms in different countries (Sellar & Lingard 2013), similar links between the economy and STEM are seen in most western countries for example in the USA (National Science and Technology Council 2013), UK (The Royal Society Science Policy Centre 2014) and New Zealand (Ministry of Education 2009). Yet while STEM is considered important to the economy, the STEM field in Australia and other countries is facing current and future shortages (e.g. Office of the Chief Scientist 2012; Department of Education 2009; Wong et al. 2016).

STEM shortages occur at various stages of the STEM education and career 'pipeline' in subtly different ways in each country. These country differences are influenced by both differences in how school systems are structured as well as sociocultural factors (Marginson, Tytler, Freeman & Roberts 2013). In Australia, the governance of schooling is distinctive. The Commonwealth government has only limited power over schooling as the management of schooling resides with the state governments. That said state governments have limited taxing power and so the Commonwealth government has used this financial mechanism to drive some specific purposes in schools (Keating and Klatt 2013). One of the most important developments in Australian schooling in recent times has been the establishment of a National Curriculum. State power has meant however that the states have each interpreted and enacted the national curriculum differently (Yates et al.2016).

For these reasons, the inclusion of STEM and the separate STEM subjects does vary across the states. Science and mathematics, in both the national and state curricula, are outlined separately as two distinct learning areas. Both technology and engineering fall under the learning area Design and Technologies (Australian Curriculum and Assessment Authority n.d.). The national and state curriculum bodies encourage the integration of disparate STEM learning areas from the beginning of schooling up until the end of year 10; however, how this is undertaken is largely decided at the individual school level. The final 2 years of schooling, years 11 and 12, where students are typically 16–18 years old, includes a high school certificate which goes by different names in each of the states. The high school certificates require students to take a selection of subjects; and at this level, integration across subjects rarely occurs due to the high stakes final exams being subject based. In these final 2 years, science, engineering and technology are not compulsory in any of the Australian states. In some of the states, mathematics is compulsory until the end of year 12. This means that many students do not take any STEM subjects or possibly only mathematics after the age of 16 years old.

In Australia, one trend that has caused concern is the decline or stagnation over the last two decades of students taking the senior secondary school STEM subjects of advanced mathematics, physics and chemistry (Marginson, Tytler, Freeman & Roberts 2013). This has led to much public discussion about the state of STEM (Education Council 2015). A number of influences have been associated with the low take up of postcompulsory STEM subjects including the perceived difficulty of these subjects and how students balance this against the utility value of undertaking the subject alongside a broader range of subjects being offered at the senior secondary level (Lyons and Quinn 2010). In Australia, subject choice is also possibly linked to university prerequisites (Office of the Chief Scientist 2012). This is seen to have a flow on effect as to how many students pursue higher education STEM qualifications and careers. This perceived gap and concern with producing enough STEM graduates to supply the future STEM labour market is therefore one of the primary focuses in discussions of STEM in government and industry documents. The decline in student take up of STEM is raised as problematic in many discussion papers internationally. In Australia, the following comments written by the Department of Prime Minister and Cabinet and the Office of the Chief Scientist in policy papers are illustrative of such discussions:

> The participation rates of Australian school and tertiary students in STEM disciplines remain a matter of concern (Office of the Chief Scientist 2014, p. 21).
>
> Too few Australian students are studying science, maths and computing in schools – skills that are critical to prepare our students for the jobs of the future (Department of Prime Minister and Cabinet 2015, p.4).

Such policy papers largely express concern with this trend and suggest that something needs to be done to rectify the decline in student enrolment. Given this decline begins at the school level, education and schools are seen as key to attracting and retaining students into STEM. In light of this, both state and federal governments in Australia alongside industry groups have released discussion papers on this issue (for example Australian Industry Group 2013; Department of Education and Training 2016; Education Council 2015; Engineers Australia 2017) and both state and federal governments and curriculum associations have responded through investment in a range of initiatives related to STEM education (for example the state government initiated MEProgram in New South Wales and Tech Schools in Victoria). A significant focus of the changes has been on the school curriculum and how this can best be supplemented or reconfigured to engage and retain students in STEM.

Government and industry group calls to ensure that there are an appropriate number of STEM graduates entering the labour market into the future has occurred in parallel to a related focus on skills in education. The following section will look at how this focus has come about and how it relates specifically to the school STEM curriculum.

3 Calls for a Focus on Skill Building and Interdisciplinarity in the STEM Curriculum

Australia, like most countries, has been through many curriculum iterations. The Australian states each have their own curriculum and unique curriculum histories that reflect various state and federal policies and trends over time (Reid & Price 2018; Yates, Collins & O-Connor 2011). Each of these curricula are concerned with what should be known about the world, have particular purposes and are the result of some deliberate choices and interests. In the current and recent context where economists emphasise the role of education as a central factor in economic strength (Sharma, 2004), discussions of an increasingly unpredictable labour market, internationalization (Rizvi 2011) and a time of great technological change (Cope & Kalantzis 2009), there have been some that have argued that the traditional subject based curriculum no longer provides students with what they need (for example Griffin, Care & McGaw 2012). One common approach to thinking about how students can best be provided for in response to a changing global and technological context is by considering alternative foundations to traditional subjects. A range of alternatives have arisen in such debates and often focus on the learning of generic skills, (also referred to as generic modes, competencies, twenty-first century skills, transferable skills) alongside or in preference to subject based knowledge (Lederman & Niess 1997; Muller, 2014; Yates, Collins & O'Connor 2011).

Internationally, this trend toward generic skills or modes of education is evident. The OECD has commissioned a number of reports concerned with the teaching of twenty-first century skills (OECD 2005; Ananiadou & Claro 2009) and a number of curricula have been designed around alternative generic modes. One example of this in Australia is the now abandoned Queensland New Basics. This curriculum had a focus on generic skills as well as being interdisciplinary and structured around four key areas (Yates, Collins & O'Connor 2011). Internationally, other examples have been introduced in Ireland, New Zealand and South Africa (see Young, 2010 or Whitty 2010 for discussion). The language of generic skills, such as the need for students to be critical thinkers and problem solvers, is now commonly found in policy discussions of the future labour market and the need to prepare students with the skills and dispositions they will need to work in the future knowledge economy (Yates & Grumet 2011). Industry groups have also published reports that express concern with the lack of skills that graduates possess and the importance of these for the future workforce (e.g. Australian Industry Group 2013; PWC 2015; Engineers Australia 2017). In government and industry discussions, the importance of STEM for the future economy, concern with declining student numbers and the need to develop students' generic skills is regularly highlighted as can be seen in the following examples from Australia:

> Use curricula and assessment criteria, from primary to tertiary levels, to promote the development of longlasting skills—including quantitative skills, critical thinking, creativity, and behavioural and social skills— in parallel with disciplinary knowledge (Office of the Chief Scientist 2014, p. 23).

> There will also be a growing need for the broad skills that STEM fosters. Critical thinking and problem solving, analytic capabilities, curiosity and imagination have all been identified as critical 'survival skills' in the workplace of the future (PWC 2015, p. 14).

The below is an international example from the UK:

> Studying STEM subjects helps young people to develop their creativity, problem-solving and technical skills, and makes them better able to make informed decisions about STEM issues (Department for Business, Innovation and Skills 2015).

Within discussions of the need for a focus on skills in education and curriculum renewal more generally, interdisciplinarity is often put forward as an alternative to a traditionally subject-based curriculum and a structure that more readily allows for the development of skills that are seen to be desirable. The following section will explore more fully the drivers toward interdisciplinarity.

4 Reasons for Interdisciplinarity

Calls for interdisciplinarity are not new in education (Barnes 2015; Beane 1997; Drake 1998; Wineburg & Grossman 2000). However, the focus and reasons for interdisciplinarity have changed over time. Julie Klein in her 1990 book on interdisciplinarity discusses that pressures for interdisciplinarity stem from both instrumental and conceptual justifications for education. Instrumental interdisciplinarity is tied to beliefs that the curriculum should reflect the needs of the economy and the labour market. This form of instrumentalism tends to focus on employability skills, utility value and practical applications of knowledge. This differs from conceptual claims for interdisciplinarity that are more philosophically driven and are guided by postmodern approaches to education. This comes in the form of theories and evidence that support unity, synthesis and integration (Millar 2016). Here, we see the long running argument that interdisciplinarity more realistically represents the world we live in where problems are complex and intertwined unlike the more traditionally subject-based curricula that are still found in most Australian secondary schools and elsewhere.

The argument for instrumental interdisciplinarity can be compared with mode 2 conceptions of knowledge put forward by Gibbons et al. (1994). In this view of knowledge, mode 1 knowledge is associated with the traditional disciplines, whereas mode 2 is more interdisciplinary and perceived as problem-based and outcome-focused (Gibbons et al. 1994; Nowotny, Scott & Gibbons 2001). This now well-known distinction while originally proposed to deal with knowledge production has become increasingly used in discussions of curriculum (e.g. Muller & Young 2014). Mode 1 versus mode 2 discussions often position subject-based curricula as outdated and use arguments about the "speed of discovery", an ability to tackle society's big issues and the unknown nature of the future workforce (Griffin, McGaw & Care 2012; Murgatroyd 2010, p. 260) as reasons to provide students with a more mode 2 skills focused and interdisciplinary curriculum. While the mode 1/mode 2 argument has been criticized as having historical, epistemological and sociological issues (Edqvist 2003; Weingart 1997), the take up of these ideas has been strongest amongst certain groups. As pointed out by the original authors, the notion of a move from mode 1 to mode 2 has been taken up most heavily by 'politicians and civil servants struggling to create better mechanisms to link science with innovation' (Nowotny, Scott & Gibbons 2003, p. 179). Given the discussion around skills, solving current big issues and preparing for the jobs of the future that is present in current moves toward interdisciplinary STEM, it can be said that an instrumental push toward STEM is present and as shown in the previous section is being driven largely by government and industry.

While instrumental justifications to reform the STEM curriculum are evident, government and industry are not the only groups to have influence on the STEM curriculum, the desire to reinvigorate the STEM curriculum also comes from within the STEM education community itself. This is particularly so for school mathematics and science given their longstanding history as subjects in the curriculum. Teachers and educators of these subjects have long been concerned about the need to engage students and for decades an increased emphasis on more progressive and constructivist techniques in an effort to do this is well documented (Millar & Osborne 1998; Tytler, Osborne, Williams, Tytler & Cripps Clark 2008). Many in mathematics and science education have long argued for a move away from the traditional teacher-centred pedagogy of the STEM subjects in schools. Traditional teaching of science has been famously described as a 'rhetoric of conclusions' (Schwabb 1962) that does not allow students to develop an understanding of how and why we should believe in a 'scientific world view' (Osborne 2006, p. 2) and moves away from traditional science and mathematics teaching, and curriculum have been attempted through various moves such as an increased focus on constructivism, inquiry or problem-based approaches, context-based learning and integration as a way of improving student engagement, learning and retention (Tytler, Osborne, Williams, Tytler & Cripps Clark 2008; Wood, Cobb & Yackel 2012)). In the past, calls for integrating mathematics and science have generally reflected conceptual or postmodernist arguments responding to concerns about overspecialisation, critiques about elite subject offerings (Teese & Polesel 2003) that the discrete nature of subject-based curricula does not reflect the real world (Boix Mansilla, Miller & Gardner 2000) and a desire to engage students in STEM and to keep them engaged for more of their education (Venville, Wallace, Rennie & Malone 2002; Fensham 2016).

One example of a move toward more interdisciplinary modes of curriculum is the STS movement of the 1970s that resulted in new curricula that attempted to draw in students through applications and issues of the time (Fensham 2016). Another example is discussed in a 1997 editorial for the American *School Science and Mathematics* journal, in which Norman Lederman and Margaret Niess, in commenting on implementations of the then recently reformed National Science Education Standards, assert that the trend in maths and science education toward 'curricula and instruction often labeled as integration, thematic and interdisciplinary' is often justified as 'our daily experiences are not organised into the various and arbitrarily defined subject matters that have dominated school curricula over the years' (p. 342).

While these conceptual arguments and justifications remain, particularly in recent years calls for STEM curricula to take on a more interdisciplinary form have also been driven by an instrumentalist view of education that is skills based, problem focussed and concerned with the labour market and economy in a way that has not been as present in the past. In Australia, there has by some accounts (e.g. Fensham 2013) been a shift away from academics and teachers having the greatest amount of influence in the development of science curriculum toward a greater influence by educational bureaucrats. This, it is argued by Fensham, is due to a market view of education where practitioners' expert contributions in curriculum development are taken only as advice rather than as the determining body for the curriculum framework (Yates et al. 2016). This reflects moves in other countries to curriculum development that is increasingly driven by government workers (Ball 1994). So while more conceptual reasons for introducing an interdisciplinary STEM curriculum are present, the current context is dominated by more instrumental justifications.

This combination of influences on STEM curriculum has resulted in STEM being increasingly spoken about as a curriculum organizer where STEM is seen as an interdisciplinary curriculum that integrates aspects of science, technology, engineering and mathematics is "relevant" and "useful" and has a focus on the teaching of generic skills and ability to prepare students for the future workforce. The term also often encompasses other subject areas such as the arts or humanities. So as discussed above, rather than STEM being just a collective name for separate siloed subject areas, STEM is instead being presented as a solution to a range of issues facing STEM at the school level.

Bernstein describes the fields of production, recontextualisation and reproduction as an 'arena of struggle' (1990, p. 206) where the different groups are each attempting to control the device. To this point, this paper has shown that the range of influences and groups invested in the current STEM curriculum in Australia has resulted in a curriculum that is attempting to provide 'a solution or settlement to multiple coexisting agendas' (Doherty, 2015) that come from a range of groups. For this reason, STEM in the school context has become a curriculum organiser that is seen to serve a range of purposes and is dominated by a discourse of generic skills, interdisciplinarity and employability. The following sections will explore the implications for schools in interpreting and implementing a STEM curriculum.

5 Purposes of Curriculum and Uptake in Schools

To this point, this paper has shown that STEM is trying to fulfil multiple purposes for a range of stakeholders. These purposes include attracting, engaging and retaining more students in STEM as well as having a larger emphasis on skills, relevance and interdisciplinarity. The multiple purposes that the current iteration of a school STEM curriculum is trying to achieve causes tensions and issues in how such a curriculum should be implemented. It is in schools and classrooms that government policies and curricula are reproduced and even for a fairly traditional curriculum, how these are taken up in schools is by no means a direct translation and is instead a complex process (Braun, Ball & Maguire 2011) that can generate 'pressure' (Ball, Maguire, Braun & Hoskins 2011, p. 614) and result in 'a concomitant set of negative emotions'. The multiple purposes that STEM is trying to achieve and include in schools compounds this problem. There is confusion amongst many in the STEM community about what a skills-based interdisciplinary STEM curriculum should look like (Wong et al. 2016) or include and given that teachers are generally trained in and committed to a limited number of subject areas, consideration needs to be made of the consequences of attempting to implement a curriculum that takes teachers beyond their knowledge base.

While the interdisciplinary STEM curriculum is a relatively recent phenomenon that has its own peculiarities, the pursuit of interdisciplinary curriculum in science and mathematics education is not new. John Dewey (1956) for example talked about the issue of learning a subject in isolation, and there have been many moves toward and away from interdisciplinarity in the school secondary curriculum since. This reoccurring curriculum emphasis and the number of often fleeting attempts to implement such a curriculum attest to how difficult it is to get right.

A consideration of the issues in a move to a more skills focused interdisciplinary STEM curriculum and some of the difficulties in implementing such a curriculum is henceforth considered. There are a number of issues that arise here that the remainder of the paper will attempt to tackle. Firstly, what is an interdisciplinary curriculum and where do generic skills fit, secondly issues in implementing interdisciplinary curriculum and lastly can this version of a STEM curriculum fulfil the multiple issues that it is trying to address?

6 Disciplinarity and Interdisciplinarity

In any discussion of interdisciplinarity, it is valuable to consider how it relates to its constituent parts—the disciplines. While the concept of disciplinarity is itself not neat, it is widely acknowledged that disciplines are stabilized by having a specialized knowledge base and methodologies that are determined, largely agreed upon and maintained through disciplinary communities that have shared training and identities (Abbott 2001; Becher 1989). Becher's (1989) widely used typology distinguishes further between pure and applied disciplines where more applied disciplines are more concerned with the application of knowledge. Pure disciplines are seen as inward looking and self-referential and oriented toward 'truth seeking' (Becher 1989; Bernstein 1996; Muller 2009). This does not mean that the pure disciplines are not concerned or do not see value in more outward facing applications of knowledge (Yates et al. 2016) rather the inward looking progression of the discipline is seen to be epistemologically significant (Muller and Young 2014). Due to the diversity of work that goes on within disciplines and the changing nature of disciplines themselves, disciplines do not always fit neatly into typologies however broadly speaking mathematics and science are considered pure disciplines whereas engineering and technology are considered to be applied disciplines (Becher 1989). Such typologies, while not perfect, are a useful way of considering some of the key differences in the ways disciplines pursue and make value judgements about knowledge. However, the self-referential nature of the disciplines is perceived by some as a limitation (e.g. Frodeman 2014). There is concern that this kind of knowledge is both elitist in the way disciplinary boundaries shut some out from the disciplines that there is a greater need today to be outward looking and to engage in the bigger issues and debates (Griffin, Care & McGaw, 2012).

While much of the thinking about the disciplines has been done in relation to the field of knowledge production, there is a strong relationship between disciplines and their related school subjects and curriculum in the field of recontextualization. Different disciplines have different knowledge structures that influence how knowledge is reproduced in curriculum. These structures 'impose constraints on appropriate curriculum form' (Muller 2009, p. 216). Like the disciplines, school subjects have provided important social and epistemic groupings

(Grossman, Wineburg & Beers 2000). However, as discussed earlier, there have over time been calls to question the subject-based structure that dominates most school systems and to replace this structure with a more interdisciplinary curriculum that reflects the 'real' world and increasingly, to more appropriately prepare students for a changeable workforce. For this reason, many discussions of interdisciplinarity are grounded in ideas of unity and synthesis, transferable or generic skills and the need to move beyond disciplinary boundaries.

Interdisciplinarity, however, is a term that brings with it confusion. In an effort to understand interdisciplinarity, a wide range of terms such as integrated, integrative, transdisciplinary and multidisciplinary have arisen as a way of trying to differentiate and describe the wide range of pursuits that can be called interdisciplinary (Dowden 2014). Many of these definitions are trying to capture the degree of integration that exists, with more integration often being portrayed as the ideal (Klein 1996), although this is sometimes disputed in the literature on interdisciplinarity (as discussed in Madsen 2018). Disciplinary integration is however in itself not necessarily clear. Disciplinary boundaries are often blurred and there is much research to show that disciplines are not static, instead knowledge, methods and theories are constantly moving across disciplinary boundaries and the disciplines are constantly shifting and dedifferentiating (Abbott 2001; Jacobs & Frickel 2009; Stichweh 1992). So while much of the discussion of interdisciplinarity assumes that it is inherently different to disciplinarity, an alternative school of thought poses that interdisciplinarity presupposes disciplinarity such that one is integral to the other (Abbott 2001; Klein 2000; Madsen 2018).

The history of major curriculum change shows that often not enough attention is paid to teachers' existing knowledge base and identity (Leggett & White 2011). Secondary teachers in Australia and internationally largely come from strong disciplinary backgrounds and often tend to identify strongly with their discipline and subject areas (Yates et al. 2016). We know through research, such as that done on pedagogical content knowledge (van Driel, Verloop & de Vos 1998), that over time teachers develop complex understandings of how best to teach particular subject areas. Discussions of interdisciplinary STEM curriculum do not always acknowledge the epistemological barriers to interdisciplinary work and how these are overcome by those collaborating in interdisciplinary curriculum development and teaching. Whether disciplines under the STEM umbrella are trying to integrate with one another or with disciplines outside of STEM, interdisciplinarity involves the need for induction into different academic discourses (Feyerabend 1993) for both teachers and students. Conversation across disciplinary boundaries requires a willingness to learn one another's disciplinary knowledge, techniques of data collection, analysis and language (Gaff & Wilson 1971). Interdisciplinary collaboration depends on a commitment to understand one another's disciplines. This presents a significant epistemological boundary for all players in an interdisciplinary project and explains why the degree of integration changes over time.

Integration of the disciplines and subject areas is therefore not straightforward but a complex and dynamic epistemic process that takes place over time and has a strong social influence (Klein 1990). There is not a single pattern for how disciplines or subjects interact and the level of integration in interdisciplinary work has been shown to change over time as teachers become more familiar with the curriculum (Petrie 1992). This makes defining interdisciplinarity difficult. In discussing the use of typologies in the social sciences, Young (2008 p. 21) suggests 'they do not tell us definitively how the world is; they identify trends and enable us to ask questions and propose hypotheses about the world', typologies should therefore act as a starting place for considering possibilities yet many debates about STEM and interdisciplinarity get stuck on appropriate typologies and pinning down the best definition. The issue with trying to categorise interdisciplinarity too strictly is that the terminology does not necessarily capture the complex temporal and epistemic nature of the disciplines and interdisciplinarity and in curriculum discussions, distracts from the fundamental questions of the purpose of interdisciplinarity, when it should be carried out, what the benefits are and what it involves.

This brings about an important issue that needs to be considered in relation to interdisciplinary STEM curricula. Underlying discussions of a move to an interdisciplinary STEM curriculum is an assumption that such a move will be beneficial. There have been some, however, that have argued that the benefits of interdisciplinary learning have as much to do with how an interdisciplinary course is taught as they do with the interdisciplinary content (Czerniak & Johnson 2014; Newell 1994; Tsui 1999) while others have suggested that 'there is no body of evidence that attests to greater learning in high quality interdisciplinary versus high-quality disciplinary classrooms' (Grossman, Wineburg & Beers 2000, p. 9). Or in the case of some aspects of STEM that learning may be reduced as has been argued for the learning of mathematics (English 2016) or that there is an 'asymmetric dependency' (Wong & Dillon 2019, p. 799) between science and mathematics that has consequences for the curriculum, given this, the following section explores content in the interdisciplinary STEM curriculum by investigating discussions of knowledge and skills in curriculum alongside ways that the curriculum can be structured for interdisciplinarity.

7 What Should Be Included in an Interdisciplinary STEM Curriculum?

The kind of knowledge that is taught in an interdisciplinary STEM curriculum, except for in examples of particular units and beyond topic headings, is not always addressed and instead there is a tendency to focus on pedagogic techniques, for example the engineering design process (Kelley & Knowles 2016) or what are considered to be the beneficial skills (Morrison 2006) that come out of interdisciplinary learning. The issue with this is that it is difficult to differentiate the benefits or otherwise of discipline based and interdisciplinary curriculum versus the pedagogical modes. Given that interdisciplinary curriculum are often presented as more forward looking it is not necessarily surprising that they often attract more progressive pedagogical techniques and so there is a need to gain a better understanding of what constitutes an interdisciplinary curriculum and why students may benefit from such studies. This reflects debates in the curriculum literature over the last 10 years to 'bring knowledge back in' (Young 2008; Moore & Young 2001, p. 446) to curriculum discussions. This position, 'brings knowledge itself back into the debate about curriculum without denying its fundamentally social and historical basis' (Moore & Young 2001, p. 446). The concern here is that in the arguments for and against curriculum change, the focus has been heavily on the learner (Biesta 2009) and on the relationship of the curriculum to social change or on the social relations to knowledge. This has resulted in a lack of emphasis on knowledge itself and why a particular kind of knowledge is included in the curriculum. This has for example been shown to be the case for curriculum in Australia (Yates, Collins & O'Connor 2011). While concerns have also been raised about this 'knowledge turn' (eg Rudolph, Sriprakash, & Gerrard 2018; Zipin 2013) that need to be acknowledged, it can be said that discussions and research on interdisciplinary STEM curricula do not tend to address the issue of what knowledge should be included in such a curriculum, particularly beyond specific units of work.

There are a number of examples of this in the literature. Bybee (2010) in his vision of STEM education for 2020 includes a range of 'curricular topics' including 'population growth' and 'impact of modern warfare' (p. 32) without going into detail about what knowledge would be included in such topics. Kelley and Knowles (2016) present a framework for integrated STEM education that includes the need for 'authentic contexts' (p. 4) as well as focussing on engineering design, technological literacy, science inquiry and mathematical thinking. This paper highlights the need for context in STEM education and particular pedagogical approaches and skills but not specific knowledge. In presenting an example of work that involved students rebuilding a damaged bridge, English (2016), while including some more specific discussion of the reasoning that was made by students, the specifics of the kind of knowledge and to what level of depth that knowledge is covered is not included. Similarly, Kennedy and Odell (2014) emphasised the need for students to be able to apply the 'science and mathematics knowledge they learn to an engineering problem and to utilise technology in finding a solution' (p. 254) and that STEM requires 'that pedagogical approaches must be altered from traditional approaches' (p. 256). This paper also takes up the idea of a problem or context as a means for framing curriculum and the need for particular pedagogical approaches without going into detail of the kind and depth of knowledge required.

While overarching topics, contexts or problems are a useful way to structure curriculum and pedagogical approaches are an important consideration, there is an absence in terms of discussing the specifics of what knowledge students need to know and to what depth. This is possibly due to the large range of knowledge that an interdisciplinary STEM curriculum could incorporate. While there is some politicisation of what are considered to be the important concepts in the traditional siloed STEM subjects (Fensham 2013), they are relatively speaking largely agreed upon due to the longer history of these subject areas and the stability of the associated disciplines. The important concepts in an interdisciplinary STEM curriculum on the other hand are not agreed on partly because the integrated possibilities are so numerous and so discussions tend to focus on useful themes that pull together subject areas or on the skills students may take away.

Another related issue is how knowledge taught within an interdisciplinary curriculum should relate to its constituent parts, the subjects. Should an interdisciplinary STEM curriculum exist in parallel to the constituent STEM subjects and if so what is the interplay between them? The role of the subject or the discipline in knowledge development is an important one to consider. While issues of power and elitism have been shown to be an issue with the disciplines and related school subjects (Teese & Polesel 2003), the structuring of knowledge within the disciplines and subjects also provides an important structure that enables access to valuable and often more abstract and theoretical understandings. This is particularly true of science and mathematics where knowledge is hierarchical in structure due to the way new knowledge often builds on previous knowledge (Bernstein 2000). The same could also be said for engineering and technology although the applied nature of these two disciplines does mean that there is a greater emphasis on application.

The disciplines play an important role in the discovery of new knowledge (Weingart & Stehr 2000, p. xi) and in reducing the complexity of knowledge by allowing for the sorting of knowledge and in doing so helps to 'achieve economy of memory' (Sokal 1974, p. 116). In this way, the disciplines and their related subjects allow us to bring some order into the complexity of knowledge. The curriculum plays an important role in deciding what knowledge is valuable to be learnt. For subject knowledge, this also means induction into the 'specialised rules of internal relations' (Bernstein 2000, p. 7) and the procedures required to gain and to validate knowledge (Winch 2013, p. 13). For that reason, many argue that 'concepts, and their systematic relationship within particular disciplines and subjects, should never be marginalized in curriculum design' (Wrigley 2018, p.12).

Also important is the way that students personally connect with concepts and the need to move 'backwards and forwards between experience and abstraction' (Wrigley 2018, p. 12). This is where we see the importance of context, 'real-world' problems, applications and relevance as being seen as important in STEM in engaging students in content (Fensham 2009; Tytler, Osborne, Williams, Tytler & Cripps Clark 2008). The connection between these and abstract concepts is important for student learning as it is the interchange between expert or disciplinary discourses and everyday knowledge that is pedagogically powerful (Bernstein 2000; Dewey 1956). The issue is that often the interplay between these two is underplayed or left out of discussions of interdisciplinary curriculum. As seen in the examples drawn from the STEM literature above, much of the research and advice on interdisciplinary teaching focusses on how to theme interdisciplinary teaching and the need for real-world or relevant problems (Bybee 2010; English 2016; Honey, Pearson & Schweingruber 2014; Kelley and Knowles 2016; Kennedy and Odell 2014) but do not address to the same extent the role of abstract or expert knowledge and how all students are provided with access to this.

The move toward relevance and context, problem and inquiry based learning has come to dominate curriculum documents and assessment design in recent years for good reason. This move reflects critiques of 'passive' pedagogies and has been advocated by the likes of Dewey (1956) and Freire (1974) as well as many within science and mathematics education as discussed earlier. Engaging students through a unit of work based around a theme or a real-world or relevant problem such as the spread of disease, air pollution or designing a bridge for earthquake prone areas, is a valuable way of respecting the diversity of students' experiences and interests across an education system and within the classroom. However, it has been shown that the implementation of relevance can also compromise disciplinary learning (Doherty 2015; Fenwick 2011; Millar 2016) and other analyses have shown that relevance can have a different meaning depending on the context (Blackmore 1990). In implementing such curricula, consideration needs also to be paid to the way abstract knowledge is drawn into such units so that all students are provided with access to this understanding over the whole course of secondary schooling. Worldwide, there is much research that shows that students are provided access to different kinds of knowledge depending on their background (e.g. Young 1971; Apple 2004) and that the use of relevance and theme-based learning is often used in low-SES schools in a way that does not allow access to abstract knowledge in the same way that more middle class and elite schools do (see Whitty 2010 for discussion). As one of the many aims of the current move toward STEM is to engage and retain a wider range of students, the kinds of interdisciplinary STEM curricula that are being implemented and the influence of these on students' understanding needs further research and consideration.

Similarly, there has been some criticism in the move to a more instrumentalist skills-based curriculum that some of the broader purposes of education and what is useful about subject knowledge is lost. Generic modes are rooted in ideas about 'trainability' (Bernstein 2000, p. 59) and preparation for the workforce. Such generic modes can be related to the mode 2 view of knowledge put forward by Gibbons and colleagues in 1994 that is instrumentalist and problem focussed. As mentioned earlier, skill-based curricula have been implemented in many countries. There are a number of criticisms of generic forms of curriculum including that 'in their most extreme form, these curricula may be devoid of any specified knowledge content' (Whitty 2010, p. 40) and that they 'insidiously suppress recognition of their own discursive base (i.e. they suppress awareness of the fact that they are themselves tacitly rooted in theory)' (Beck 2002, p. 623) and that socially disadvantaged students are further disadvantaged by such approaches (Young 2010). The value of the underlying knowledge foundation is often forgotten in discussions of skills and there is mixed evidence to suggest that generic skills or modes can be 'acquired, taught or assessed separately from specific domains with their specific contents and contexts' (Young 2010, p. 4). Further research and discussion is needed to understand how a focus on skills works alongside interdisciplinarity and the STEM disciplines in a way that provides for both the future workforce and the STEM literacy of the population.

These last two sections have shown that in moves toward both an interdisciplinary and more skills focused STEM curriculum that there are some serious epistemological and social implications. These are not necessarily impossible to overcome, however, they need consideration if this kind of curriculum is to truly succeed in engaging all students in STEM.

8 Conclusion

Discussions of curriculum raise questions about what education is for. They deal with questions of identity, knowledge building and epistemology and contestations over what and who should be included in curriculum and what and who is excluded. The current trend toward interdisciplinary STEM curricula in Australia and internationally reveals a range of sometimes complementary and sometimes conflicting purposes. These purposes offer both possibilities and tensions while also showing that there are a number of unquestioned assumptions about the benefits of a STEM curriculum.

The aim of this paper was to investigate the various influences that have led to current interpretations of the school STEM curriculum and possible issues and questions that arise from implementing such a curriculum. It is clear that the term STEM when used in relation to the school curriculum is a term that encapsulates a range of purposes and meanings as stakeholders in STEM education each attempt to impart the values important to them. This has resulted in STEM being seen as a curriculum organiser that is interdisciplinary and skills focused and attempts to engage and retain students in the STEM field. The presence of instrumentalism as a driver for curriculum change is also present in a way that may not have been so dominant in previous iterations of science and mathematics. The second part of this paper has attempted to raise some of the issues that arise from such a curriculum. In doing so, it is possible that this paper has raised more questions than it has answered. It is not the aim here to dismiss a move toward different kinds of STEM curriculum but rather raise the possibility that there are some very real difficulties that come from such a curriculum change. These difficulties require further research and consideration.

In particular, the paper has raised questions about the interplay and tensions between knowledge and skills, disciplinarity and interdisciplinarity and how each of these requires attention to be paid to epistemology and how moves toward one or the other do or do not engage particular groups of society with STEM. It would seem that a careful balancing act is required to develop a successful and sustainable STEM curriculum; yet, more research is needed in order to successfully navigate these issues.

There are two avenues in particular that have been raised that would benefit from further exploration:

- The first avenue is an ability to voice what unique understandings of the world arise from specific interdisciplinary learning. What is it that interdisciplinary learning provides that is different or adds to disciplinary subject based learning? Ideally, this question needs to be answered independently of any discussion of pedagogical techniques.
- The second avenue has to do with how interdisciplinary learning is best undertaken paying attention to some of the epistemological questions raised in this paper. The unique epistemologies of the different STEM disciplines need to be taken into account here as well temporality and the interplay between depth and breadth of knowledge. At the most basic level, how do the pure disciplines of science and mathematics integrate compared to the applied disciplines of engineering and technology? Do the different ways that these disciplines legitimate and structure knowledge have implications for how they can work together in a curriculum? What is the role of time in understanding and bringing together knowledge, techniques of data collection, analysis and language from a range of disciplines for both teachers and students? And how do we go about balancing the depth and breadth of knowledge required to develop an interdisciplinary understanding while not losing what is valuable about the disciplines?

Threading through both of these avenues there must be consideration of whether changes in curriculum structure will disadvantage particular groups of students. Research in these areas will provide a clearer picture of both the benefits of interdisciplinary STEM as well as how interdisciplinary STEM should be structured within the curriculum.

The history of curriculum moves shows that change is difficult. If STEM is to be successful a deeper understanding of these complex issues is required alongside a longer term willingness by government and education departments to invest the time required for teachers and curriculum developers to navigate the many tensions and complexities raised.

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