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Ryder, J orcid.org/0000-0002-2741-0152 (2015) Being professional: accountability and authority in teachers' responses to science curriculum reform. Studies in Science Education, 51 (1). pp. 87-120. ISSN 0305-7267

https://doi.org/10.1080/03057267.2014.1001629

Being professional: Accountability and authority in teachers' responses to science curriculum reform.

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Abstract

The science curriculum is a focus of repeated reform in many countries. However, the enactment of such reforms within schools rarely reflects the intended outcomes of curriculum designers. This review considers what we know about the experiences and reflections of teachers in the enactment of externally driven school science curriculum reform. 'Externally driven' signals a focus on studies of teachers who did not make a proactive choice to adopt a particular curriculum reform initiative. This is a very common experience for teachers in many school systems, and one likely to highlight issues of professionalism and authority that are central to the work of teachers. The review analyses 34 relevant studies. These include studies of teachers' experiences of national curriculum reform, and also studies focusing on more regional or local curriculum reform activities. The studies examine individual teacher's beliefs, practices and reflections associated with curriculum reform, the response of teacher communities to reform (e.g. within school departments), and teachers' (and other stakeholders') experiences across school systems. A wide range of factors influencing teachers' responses are identified. These are characterised in terms of personal, internal and external contexts of teachers' work. The review also highlights issues of authority, professionalism and the process of meaning-making in response to external curriculum reform. The discussion section identifies important areas for future research and gives recommendations for the design of curriculum policies that recognise and support the professionalism of science teachers.

Introduction

There have been, and continue to be, persistent attempts to change the school science curriculum. This constant change is an inevitable outcome of the 'contested terrain' of science curriculum policy, with changes reflecting shifting power and influence amongst various stakeholders (DeBoer, 2014, Fensham, 2009). These curriculum reforms have a significant impact on the work of teachers, and the classroom experiences of students. It is also clear that the enactment of curriculum reforms within schools and classrooms rarely reflects the intended outcomes of those designing the curriculum reform (Kahle, 2007). Thus, given the constancy of change, the significant impact on practice, and the mismatch between reform intention and teacher activity within schools, the formation and enactment of science curriculum reform is a major education policy issue.

Collected handbooks on science education research tend to be structured around headings such as: student learning and conceptual change; science teaching; teacher education; curriculum and assessment; informal learning; literacy/language (e.g. Fraser et al., 2012, Lederman and Abell, 2014). Many of these sections include significant scholarship and debate around the purposes of school science education. However, there has been noticeably less research focusing on the processes of science education policy – its formation and enactment within schools. Indeed, deBoer goes further: 'there is virtually no literature in science education on how research affects policy, how policy affects practice, or how the personal values of teachers, parents, administrators, and students are relevant to policy enactment or implementation' (deBoer, 2011, p. 2). This review addresses aspects of deBoer's concerns in the policy context of science curriculum reform by asking: what do we know from research studies about the experiences and reflections of teachers in the enactment of externally driven school science curriculum reform? 'Externally driven' signals a focus on studies of teachers who did not make a proactive choice to adopt a particular curriculum reform initiative; a common experience for many teachers. Whilst there have been previous reviews with a similar focus these have been smaller in scope, and are becoming dated (Aikenhead, 2006, Keys and Bryan, 2001, Anderson and Helms, 2001).

In recent years there have been significant developments in the conceptualisation of the outcomes of externally driven school science curriculum reform. An influential 'stage model' of educational innovation scale-up has been developed by the Institute of Educational Sciences, Department of Education in the US. An initial design stage is followed by 'efficacy studies' examining impact under favourable conditions, 'effectiveness studies' undertaken in a broader range of 'typical' educational contexts, and large-scale randomised controlled trials (Lee and Krajcik, 2012). A key focus within these stages is 'fidelity of implementation'; a measure of whether what the teacher does in the classroom is consistent with the intentions of curriculum developers (O'Donnell, 2008). The empirical focus of such studies tends to be on student learning outcomes and fidelity of implementation by teachers (e.g. Lee et al, 2009). However, there is less attention given to examining in detail the experiences, motivations and reflections of teachers, and how these might change over

time. By contrast Penuel and Fishman (2012) have emphasised the importance of studies that aim to *learn from* the variations of implementation of educational innovations across settings. The outcomes of such 'design-based implementation research' (DBIR) aim to support curriculum developers and professional development leaders to 'focus their efforts on helping teachers make productive adaptations of materials by being responsive to students' (p284). The appropriateness of a strong focus on fidelity of instruction is also challenged by accounts of curriculum enactment that emphasise the inevitable role of teachers in enacting external curriculum reforms in their educational contexts (Ball et al., 2011, McKenney et al., 2006). These perspectives see curriculum reform policy as constituted in the developing activities of teachers as they enact policy texts in specific settings. Thus, the detail of implementation is the necessary responsibility of the teacher, rather than something that can be presented to the teacher for them to 'deliver'. This review focuses specifically on the findings of empirical studies which include detailed data collection and analysis of the developing experiences, motivations and reflections of teachers as they respond to externally driven science curriculum reform.

A focus on science in particular raises distinctive issues that are less significant in many other curriculum subject areas. Science is a compulsory school subject in most countries, typically alongside study of official country language(s) and mathematics. Thus school science has a privileged and distinctive status and is therefore prominent within the school curriculum (e.g. in terms of curriculum time, resource allocation). Alongside literacy and mathematics, science education is often linked to economic progress, giving it a broader and highly political significance (National Academy of Sciences, 2010). Indeed, pronouncements of science education policy often appear more as economic policy, as in 'Europe needs more scientists' (European Commission, 2004). Thus, science is a school subject with many differing stakeholders and is therefore subject to continual and varied school curriculum reform initiatives. This often results in very powerful and visible accountability mechanisms, such as the publication of 'league tables' of schools in England based on student attainment outcomes. Furthermore, curriculum reforms have often involved significant shifts in the scope of science as a school subject, for example introducing teaching/learning about the history and philosophy of science, or decision making in the context of social issues with a science dimension (Donnelly and Ryder, 2011). Such shifts are characterised by McKenney et al. (2006) as a series of 'waves' of curriculum renewal (p. 71). These changes in the representation of 'their' subject within schooling have major implications for teachers' identities as professionals (Luehmann, 2007). Another distinctive feature of science is the dynamic nature of the subject itself – with topics such as nanotechnology and bioinformatics filtering down from contemporary professional science into the school science curriculum (Gelbart and Yarden, 2006, Hingant and Albe, 2010). Thus, teachers of science are experiencing continual and significant reform of the school curriculum (often as a result of reform goals driven by external stakeholders) over which they have little, if any, control.

Scope of the review

This review examines empirical studies that include an in-depth focus on teachers' experiences of, and reflections on, externally driven science curriculum reform. These studies typically use extended interviews with teachers to probe their personal teaching goals and how these interact with curriculum reform enactment, and also their reflections on broader influences on this enactment from within their school and beyond. Such studies go beyond classroom observation data typical of fidelity of implementation studies (Plass et al., 2012). They focus on why teachers respond as they do, rather than simply what they do in the classroom. Furthermore, the review does not include studies that provide surface-level insights into teachers' experiences, for example through largely closed-response written questionnaire surveys (e.g. King, 2001). Allowable contexts of science curriculum reform are broadly interpreted. Content-focused reforms that emphasise distinctive curriculum areas, such as the nature of science and/or socio-scientific issues, are included. In addition broader reforms that involve shifts in both content and pedagogy are also considered, for example reforms encouraging teachers to adopt 'science enquiry' practices in the classroom. This results in a wide range of curriculum reform contexts. In many cases the reform introduces changes to statutory national specifications of curriculum content. In other cases the reform is focused on teachers using designed lesson plans and associated resources within a single topic area. However, the key characteristic for this review was that teachers had to experience these reforms as external to their workplace. Here external is operationalised in terms of three, overlapping, required criteria: a) the *origin* of the reform is external to the school (e.g. a national curriculum policy); b) the *development* of the reform did not involve the teacher (e.g. teachers were not part of a school-based development group working with a local university); c) the *authority of adoption* is external to the teacher (i.e. the teachers in the study did not proactively choose to adopt the reform; rather this decision was made at national/state/district level, or by *other* teachers within their school).

Application of these criteria leads to the exclusion of many studies of teacher change within curriculum reform projects. Criterion (a) excludes studies of teacher change arising from in-school curriculum development activity; contexts shown to often result in significant and sustained curriculum change (e.g. Bulte and Seller, 2010). Criterion (b) excludes the many studies of the enactment of curriculum materials by teachers involved in a curriculum development group co-ordinated by a local university (e.g. Ametller et al., 2007, Rivet and Krajcik, 2004). Finally, criterion (c) excludes studies of the experiences of teachers who have *proactively chosen* to adopt a curriculum package developed elsewhere. This is a common context of teachers' experiences of curriculum change. For example, there are many studies of teachers and whole departments pro-actively adopting curriculum reform initiatives often including involvement in an extensive professional development programme (e.g. Hewson et al., 2001, Enfield et al., 2008, Banilower et al., 2007, Sato et al., 2005). One

challenge in identifying studies for this review was that many studies do not elaborate on the processes through which a school department 'chooses' to adopt a curriculum reform package. For example, was the 'choice' largely influenced by a charismatic head of department, or a small group of teachers enthusiastic about the reform? In such cases at least some of the teachers in these schools will indeed be experiencing the reform as external. The emphasis in this review is on studies in which it is clear that at least some of the teachers involved did not proactively choose to adopt the reform.

Although they lead to the exclusion of many curriculum development and teacher change studies, the three 'external' criteria are highly significant for schools and the teachers within them. Reforms experienced as external may work against the personal concerns and goals of teachers; perspectives that are fundamental to their practice (Goodson, 2013). Such reforms may also clash with the priorities, activities and ethos of schools, interacting in complex ways over time with local constraints and affordances within these social organisations (Cuban, 1995). Teachers' sense of professional autonomy may also be challenged by curriculum reforms experienced as external. Of course, in many cases teachers may immediately, or over time, embrace externally driven curriculum reform initiatives, taking ownership of the reform. However, such a response is not universal, and even then the process of enactment is rarely, if ever, a simple process of adoption of pre-formed curriculum initiatives (Ball et al., 2011, Lynch et al., 2012). For these reasons the distinctive focus in this review on teachers' responses to externally driven curriculum reform is much-needed, with the potential for insights of broad significance for future curriculum reform and the role of teacher professionalism, accountability and autonomy within the reform process.

Methods of selection and analysis

The main focus is on studies published since 2000, thereby building upon two similar reviews published in 2001 (Keys and Bryan, 2001, Anderson and Helms, 2001). However, several earlier studies with a particularly strong focus on teachers' experiences of external reforms are included to provide an historical background. In doing so it is recognised that studies from the 1980s and 1990s may be set in policy contexts very different from today, particularly with respect to the prevalence of national or state-wide testing regimes and international league tables based on student attainment.

The main sources of empirical studies are peer-reviewed journals, with some books and edited collections. Initial feasibility and scoping activity identified a set of commonly-referenced studies (e.g. Cronin-Jones, 1991, Leander and Osborne, 2008, Olson, 1981, Roehrig et al., 2007). References to other literature within these studies identified additional sources. This resulted in around 25 relevant studies. A more formal web-based search was then conducted using Web of Science and ERIC. Journal-specific searches were also conducted, e.g. Journal of Curriculum Studies, Curriculum Journal, Curriculum Inquiry.

Examples of keyword and title searches include: scien* AND national curric*; scien* AND implement*; curric* reform; teach* AND reform etc. However, given the breadth of reform contexts, it is likely that many relevant studies have not been included in this review, particularly those better known within specific countries. In part, one purpose of this review is to highlight the significance of externally driven reforms for teachers' work, and to encourage readers to highlight and draw together relevant studies in future publications.

Many publications fitting the search criteria were excluded because the study included insufficient, or poor quality, insights into teachers' experiences, or because insufficient detail was provided about the extent to which the teachers involved were external to the reform. The final 34 studies are each explicit that teachers involved were experiencing the curriculum reform as external following the three criteria introduced earlier. For some studies only a sub-set of the teachers involved were experiencing the reform as external. In such cases, the analysis here draws only on insights from these teachers.

Table 1 provides an overview of the 34 studies. Notes on the nature of the curriculum reform demonstrate the broad range of reform contexts included in this review. In a few cases the reform context is not explicitly labelled by the authors as science (e.g. geography in Cotton, 2006; 'health and physical education' in Kirk and MacDonald, 2001). However, closer reading shows that science content features strongly in these studies. The curriculum notes in Table 1 draw heavily upon reform descriptions used by study authors. For example, references to scientific literacy, epistemology of science, nature of science, science enquiry, activity-based pedagogy and constructivism reflect the terminology and related conceptual frameworks used in the studies. One notable outcome of this analysis is that many studies of teacher experiences of reform provide limited elaboration of the nature of the reform itself.

Roberts (1988) has provided an oft-cited characterisation of the varying purposes of science education in terms of seven 'curriculum emphases'. These can be used to provide a broad overview of the focus of the curriculum reforms in Table 1. Overall, there is a prevalence of reforms reflecting the curriculum emphases 'science, technology, decisions', 'scientific skill development' and 'structure of science'. In contrast, curriculum emphases 'correct explanations' and 'solid foundation' are much less evident. The reforms within many of the studies tend to reflect the goals of scientific literacy (Roberts and Bybee, 2014), and the increasing humanisation of the school science curriculum (Donnelly and Ryder, 2011). The studies also reflect a broad range of implementation contexts. In some cases teachers within school science departments are responding to reforms 'on their own' without explicit support or guidance from others (e.g. in response to national curriculum reforms as in Lunn and Solomon, 2000). In other cases teachers are working with 'mediators' of reform working within schools as explored in a later section (e.g. Leander and Osborne, 2008).

Nine of the studies are set within the primary sector (up to age 11), 20 within secondary (age 11-16) and five within upper-secondary (age 16-18). The studies have a broad geographical scope but with a significant emphasis on the US (12) and countries within Europe (13). Only two countries (South Africa and Singapore) are not within the OECD country grouping. The prevalence of the US (12), England (7), Scotland (3) and Australia (3) reflects the focus here on studies published in English. Future reviews could usefully draw upon additional studies within specific countries which tend to be published nationally rather than internationally and are often written in languages other than English.

For each empirical study the author compiled notes addressing the following issues: details of reform context; study methodology and design; theoretical perspectives drawn upon and/or developed; and findings relevant to the focus of the review. This was followed by analysis of the notes on research outcomes across all of the studies. The purpose of this cross-study reading was to identify a smaller set of themes that captured the main outcomes from the 34 studies. This resulted in the following analytical themes: 1) the range of factors influencing teacher response; 2) issues of authority and professionalism; 3) teacher response as 'meaning making'.

All of the studies addressed the first theme: factors influencing teacher response. In some cases this was an explicit outcome of systematic analysis by the study authors (e.g. Fernandez et al., 2008, Miller et al., 2010, Ryder and Banner, 2013). In other cases these factors could be seen within quotes and associated analytic themes. Fewer studies focused on the second theme: analysis of teacher authority and professionalism. However, in most of these studies this theme was identified explicitly by the study authors, for example 'authoritative science curriculum standards as barriers to teaching and learning' in the title of Wallace (2012), 'science teacher professionalism and Sc1' as a section heading in Donnelly et al. (1996) (p. 218). Only five of the 34 studies focussed explicitly on the third theme: teacher response as 'meaning making'.

The following section provides an overview of the different methodologies followed in the 34 studies. To support this section Table 1 provides short notes on research methods used for each study. This is followed by individual sections elaborating on each of the three analytical themes. For the second and third themes all relevant studies are cited, with selected exemplar studies discussed in more detail.

Reflections on methodology followed within the studies

The designs of each of the 34 studies reflect many distinct methodological commitments. These reveal the differing ways in which authors conceptualise teachers' experiences of curriculum reform. Many studies focus on individual teacher beliefs or identity and how these frame responses to external science curriculum reform. Other studies consider

working practices amongst teachers within a school science department as a significant feature of teachers' experiences of curriculum reform, emphasising the role of social interaction with peers, and associated power relations, in framing teacher experiences of reforms. Finally, several studies analyse the responses of actors beyond the school environment, and/or between several schools within a local school system, locating individual teacher's experiences within a more systemic perspective. The aim of this section is to draw out the significance of these differing methodological commitments for the kinds of issues likely to predominate in an analysis of teachers' experiences.

The individual teacher

In an early study of curriculum enactment Cronin-Jones (1991) examines two middle school teachers' experiences of implementing a 20-lesson curriculum package on wildlife conservation in the US state of Georgia. The study draws upon researcher field notes and teacher interviews conducted over a six week period. Analysis identifies the salience of four areas of teacher beliefs for their enactment of the externally designed curriculum package: how students learn; teacher role in the classroom; student ability levels; and the relative importance of content topics. As an example of the latter, one of the case study teachers, Shelley, is reported to have resisted aspects of the curriculum package addressing values and attitudes since, for her, 'fact acquisition', vocabulary and definitions were the most important curriculum foci. Similarly, Cotton (2006) identifies the importance of teachers' beliefs for their responses to a requirement to teach controversial environmental issues (e.g. indigenous people's land rights in local rainforest). This study involves a series of interviews over two years with three teachers working in different secondary schools in the UK. The study identifies a mismatch between the external curriculum emphasis on 'promoting' environmental goals and these teachers' desires to provide students with a 'neutral' or balanced perspective on these issues. In both of these studies, particularly in Cronin-Jones (1991), teacher beliefs are presented as coherent and fixed. These studies provide limited consideration of how such beliefs may have changed, and be changing, over time. Furthermore, whilst the factors underpinning these developing beliefs are evident in many of the teacher quotes provided (e.g. the focus of external assessment procedures) such factors are not reported in detail, or emphasised as analytical outcomes.

Mitchener and Anderson (1989) is another early study 'examining curriculum from the teachers' frame of reference' (p. 352). They provide case studies of how 14 teachers across two secondary schools enact an innovative science-technology-society (STS) curriculum over six months in a suburban area of Denver, in the US state of Colorado. Teachers are characterised as accepting, altering or rejecting the reform. This typology of response follows similar schemes provided in other studies (Kim et al., 2013, Roehrig et al., 2007). Mitchener and Anderson (1989) do not examine teacher response as a process that may be developing over time (e.g. from initially accepting to beginning to alter, or initially altering but now rejecting). In contrast, such processes are evident in many more other studies cited

later in this review. Mitchener and Anderson (1989) do provide a set of themes that feature in teachers' reflections concerning the STS curriculum. Several of these themes feature strongly within subsequent studies of curriculum reform responses: concern about the changing nature of curriculum content; uncertainty around appropriate assessment practices; the challenge of matching differing student needs; and confusion over the role of the teacher.

Several studies focus on individual teachers through the lens of teacher identity (e.g. Kirk and MacDonald, 2001, Leander and Osborne, 2008, Ryder and Banner, 2013). For example, Ryder and Banner (2013) analyse interviews with 22 teachers from 19 schools in England. These teachers are responding to a statutory national curriculum reform that emphasises the teaching of socio-scientific issues and the nature of science, alongside the teaching of canonical science knowledge. Several of these teachers expressed strong commitments to specific identities: 'the kind of person one is recognised as being' (Gee, 2001, p. 99). For example, one teacher stated: 'I'm a scientist and I like the science'. Reflecting on his enactment of the national curriculum reform this teacher emphasised the importance of teaching canonical science knowledge; he was sceptical about the inclusion of socio-scientific issues. By contrast, a second teacher stated that 'the science aspect of it is sort of a means to an end for me (…) it's the teaching aspect of it I enjoy rather than the science', primarily identifying as a teacher rather than a scientist. This is consistent with his main concern of how the revised curriculum impacts on student motivation, rather than the changes to the science content. However, there is limited consideration in these studies of how identity can be seen as, at least in part, *constituted by* social and institutional structures, rather than simply an individual characteristic of the teacher (Luehmann, 2007, Day et al., 2006).

Teachers working within departmental groups

In contrast to studies that consider individual teacher beliefs or identity and how these frame responses to external science curriculum reform, several studies focus explicitly on how the enactment of an external curriculum reform is reflected in, or mediated by, teacher interaction within school science departments (e.g. Melville, 2008, Rigano and Ritchie, 2003), often with an emphasis on leadership practices (e.g. Larkin et al., 2009, Melville et al., 2011). Here an individual teacher's experience of a reform is located within a departmental response; as constituted through social interactions.

Melville (2008) is a striking example. Rather than the more typical use of teacher interviews, the main data in this study are audio recordings of regular school science department meetings over a two year period, supplemented by school documents (e.g. school newsletters). These secondary school teachers are enacting a cross-curricular emphasis on 'Essential Learnings' (thinking, communicating, personal futures, social responsibility, world futures) in the state of Tasmania, Australia. The emphasis is on the 'processes by which

science teachers attempted to negotiate a sense of meaning for the reforms within their work context' (p. 1185). A key contribution of this study is its use of narrative methodology to elucidate the importance of language within the reform process, emphasising the problem of a 'linguistic distance' between the often vague and general language of the Essential Learnings reform and the precise, contextualised language of science. By examining group working practices over two years this study demonstrates how meaning making around this external reform was a collective process over time. Melville argues that too many studies focus on teacher change as solely involving the development of teacher knowledge and beliefs, and that studies do not engage sufficiently with 'the intensely cultural nature of teaching' (p. 1187). The longitudinal data collection design also provided the opportunity to track changing responses to the curriculum reform. For example 'one of the harshest critics of the Essential Learnings [reform]' (p. 1194) changed his/her view as a result of involvement in a school-wide event to showcase the outcomes of student research in science.

Melville et al. (2011) and Rigano and Ritchie (2003) focus particularly on the role of science department leaders in the context of a school response to external curriculum reform. These studies again emphasise the enactment of reform as a collective endeavour, but also highlight the key role of departmental leader. Rigano and Ritchie (2003) describe how Mr Murphy, a radical and innovative science department head, worked with more conservative and traditionally-minded teachers in his department to enact the student-centred approaches associated with a reform of the junior science curriculum in Queensland, Australia. The study shows how Mr Murphy drew upon internal resources within the school, such as a sympathetic school principal and supportive student voices, to negotiate around potential barriers to reform over time. In two case studies, based on retrospective narratives in the context of enquiry-oriented reforms in Ontario Canada, Melville et al. (2011) demonstrate the key role of the departmental leader in framing a school response to reform. Both leaders emphasise the role of departmental collegiality in the enactment of reform. Indeed, the external imposition of reform appears to have encouraged enhanced collegiality: 'we didn't know how to go about it, so we started talking' (p. 2282). These interactions appeared to support meaning making around the reform, as reported by one head of department, Dan: 'it's the conversations amongst teachers that bridge the theory/practice gap' (p. 2283). Again, the extended timescale in these analyses (several years) results in identification of the processes through which these leaders and teachers negotiate and utilise internal school structures in their enactment of external reform.

Systemic analyses

Several studies consider the role of actors beyond the school environment, sometimes across schools within a local school system (e.g. Kelly and Staver, 2005, Penuel et al., 2009, Roehrig et al., 2007, Teo, 2012). For example, Roehrig et al. (2007) examine the response of several high schools within an urban school district (Ocean Valley) in the US. This district is

implementing the National Science Foundation (NSF) funded Living by Chemistry curriculum package, characterised by real-world contexts and learning by enquiry. The study involved 27 teachers across 12 schools, within the 15-school district. Each teacher was observed 6-8 times over one year, with a terminal interview. Part of the analysis in this study focuses on the role of administrators assigned to six of the schools (those with low academic performance) to supervise the enactment of Living by Chemistry in the science department. In some cases these administrators were ineffective in supporting teachers. However, in some schools they were able to support the development of active 'professional learning communities' (p. 902), leading to effective enactment of the curriculum scheme. The Ocean Valley study also provides striking examples, in four schools, of the ways in which distinct reforms operating within a school at the same time ('concurrent reform initiatives') can interact to either support or constrain the enactment of a specific reform like Living by Chemistry. For example, a policy requirement to improve standardised test scores in specific schools led to whole school leaders in some schools questioning the 'academic rigor' of the Living by Chemistry curriculum, leading to a very limited enactment of many of the distinctive features of the curriculum package.

Penuel et al. (2009) consider the enactment of another NSF-funded curriculum package in the US state of Alabama. The GLOBE reform initiative provides curriculum materials, and an online database, for the teaching of earth sciences for students up to eighth grade. In contrast to the largely interview-based approaches of other studies, this study provides a detailed examination of teacher experiences through questionnaire responses from 225 teachers across 51 schools. Analysis includes descriptive statistics and multilevel linear modelling techniques to examine, for example, the relationship between individual teacher's perceptions of the curriculum package and their experiences of support. One striking finding is that: 'professional development had little impact on teachers' perceptions [of the curriculum] or on protocol implementation' (p. 671). Professional development activity included workshops and access to mentors for classroom-based support. This finding runs against the common assumption that an appropriate response to 'failed' curriculum implementation is more professional development activities for teachers. Penuel et al. (2009) argue that what is missing here is a closer consideration of the distinctive needs of teachers and schools working in different contexts. Consistent with this argument, their study found that longer time allocated within schools for planning their response to the GLOBE reform was linked with improved teacher perceptions of curriculum implementation.

Teo (2012) provides a distinctive example of a systemic scope in the analysis of curriculum reform enactment. This is a case study of the experiences of a school teacher, Donald, as he enacted an enquiry-based advanced chemistry curriculum in the US. Observations and interviews with this teacher were conducted over one year. Such an approach is typical of other such studies. However, a distinguishing feature of this case study is the addition of interviews with other actors associated with Donald's workplace: two school administrators,

a member of the school governing board, a student and this student's mother. The contribution of this additional data collection is in: 'illuminating the coherences and contradictions in viewpoints on the goals and outcomes of curriculum innovation' (p. 660). Donald's is a case study of a 'failed' curriculum implementation; he did not achieve his aim to change his practice in alignment with the enquiry-based advanced chemistry curriculum. The systemic analysis approach used in this case study shows that some of the reasons behind this 'failure' were the suppression of Donald's personal enthusiasm for the reform by internal school structures, particularly student, parent and school administrator expectations of a more traditional curriculum providing preparation for standardised external assessments.

This review of the methodologies employed across the studies highlights the significance of the links between conceptualisations of teacher response, methodological commitments, study design and scope of findings. The following sections turn specifically to study findings to elaborate on the three analytical themes of this review: the range of factors influencing teacher response; issues of authority and professionalism; teacher response as 'meaning making'.

Factors influencing teachers' responses

Several studies provide a list or typology of the range of factors influencing teachers' experiences of curriculum reform (e.g. Fernandez et al., 2008, Miller et al., 2010, Ryder and Banner, 2013). However, all of the 34 studies provide some insight into influential factors, even if this is not an explicit focus of the analysis. Table 2 is a summary of factors identified within the studies in this review. A typology of 15 influential factors following from a study by Ryder and Banner (2013) was used as a starting point. The author read each of the 34 studies seeking to either corroborate influential factors within Ryder and Banner (2013), or to add new elements. This resulted in the enlarged set of 27 influential factors in Table 2. The categorisation in terms of *personal* contexts specific to the teacher, *internal* contexts within the science department and school, and *external* contexts extending beyond the school, originates from Goodson's analysis of the role of statutory educational reform in the lives of teachers (Goodson, 2003).

[Insert Table 2 here]

Personal factors: Teacher focus

It is common for curriculum reformers to ascribe any failure of a particular reform to issues specific to the teachers involved, such as teacher knowledge, skills and beliefs. Of course teachers' subject knowledge and pedagogical skills, and the extent to which these meet the needs of a particular reform, are central to the outcomes of the reform (Bryce and Gray, 2004). So too are teachers' beliefs about the educational goals espoused in any curriculum

innovation (Cotton, 2006, Cronin-Jones, 1991). For example, Vos et al. (2011) provide case studies of how four secondary school teachers in North Rhine-Westphalia, Germany, enact materials from the Chemie im Kontext curriculum development programme. In the terms of this review, three of these teachers experienced this reform as external (Teacher II, III and IV). Vos et al. (2011) include an examination of the significance of value congruence: the coherence between teacher and designer values on specific aspects of the reform. For Chemie im Kontext these values include how students learn, and the role of contexts in teaching and learning chemistry. These case studies demonstrate that strong value congruence is a necessary factor for teachers to change their practice to match the intentions of curriculum designers. Perhaps not surprisingly the strongest value congruence was found for Teacher I who had been involved in the development of the Chemie im Kontext materials.

Internal factors: School focus

However, the studies reviewed here demonstrate that to fully understand teachers' responses to externally driven reform we need to move beyond a focus on personal characteristics of the teacher, and also recognise how broader issues and structures can condition teacher responses. Indeed in the study introduced above, despite the strong value congruence of Teacher I, an internal structural factor (class timetabling) resulted in limited alignment of teacher enactment with designer intentions (Vos et al., 2011). The need to consider broader aspects of the teachers' workplace setting is also identified in two studies from the 1980s (Benson, 1989, Olson, 1981). For example, Benson (1989) conducted extensive lesson observations, and an end-of-unit interview, with three teachers in one Canadian high school over a four week period. These biology teachers were drawing upon a government curriculum guide as they introduced grade 12 students to conflicting theories of plant nutrition. Benson argues that whilst teacher knowledge and beliefs were important: 'institutional factors colour this knowledge and in this way partially determine the curriculum presented to students' (p329). These institutional factors include the pressures of teacher accountability through external provincial assessments of student attainment and a perceived requirement to follow 'legally binding' provincial curriculum guides very closely.

Squire et al. (2003) provide an insightful analysis of how an externally designed curriculum becomes contextualised in distinctive ways within local classroom cultures. They followed four teachers (further details below) as they enacted a project-based, technology-rich environmental science curriculum unit in the US. Data collection involved classroom observations, pre and post-lesson interviews with teachers, interviews with students and documentation analysis. The main finding of the study was that these teachers needed to contextualise the curriculum materials to the local classroom culture by responding to local features of classroom culture such as students' needs and goals, teachers' goals and values, and local cultures such as a strong focus on student attainment grades. Rather than

identifying these adaptations as potentially weakening the reform implementation, these processes were seen as a necessary part of the effective enactment of an external reform within differing local contexts.

A distinctive feature of Squire et al. (2003) was that whilst two of the four teachers in their study had had a role in the development of the curriculum unit, two of the teachers were experiencing the reform as external. Thus, Squire et al. (2003) provide, to some extent, a comparative study of how a reform is enacted by teachers either internal or external to the reform development. This is not a strictly comparative study as all teachers are working in different teaching contexts. Nevertheless, the authors do provide some commentary on the significance of these teachers being either internal or external to the reform. They discuss the case of Luke, a teacher who had been part of the curriculum design team. Luke was largely successful in engaging his students in the project-based curriculum. However, he later reflected that his position as an 'insider' to the reform resulted in what he considered an unhelpful tendency to 'stick to the book'. He stated that in the future he would work more to adapt the curriculum approach to local contexts. By contrast, those teachers experiencing the reform as external were immediately seeking to contextualise the reform to their own classroom cultures.

Hughes (2000) demonstrates how students' interpretations of what counts as appropriate science curriculum content can also condition teachers' responses to curriculum reform. Hughes examines how two secondary school teachers experience the enactment of the Salters' Advanced Chemistry qualification in England. This post-compulsory qualification for 16-18 year olds emphasises science knowledge within social contexts, e.g. chemistry and air pollution. It focuses strongly and consistently on contextualising the teaching of chemistry within real-world applications that are considered to be socially relevant (Campbell et al., 1994). The two teachers in this study found that they needed to respond to challenges from some of their students that discussing science within socially relevant contexts did not match student expectations of 'proper' science as being abstract and factual. This student response influenced the teachers' classroom practices. For example, one of the teachers was reluctant to develop her teaching of the nature of science because she felt that her students would consider this a move away from 'factual' science and an indication that she did not 'know her stuff' (p. 437).

External factors: Systemic focus

The powerful influence of external assessment regimes features in many of the studies (Hughes, 2000, Kim et al., 2013, Zembylas, 2004). For example, Kim et al. (2013) provide an analysis of teachers' experiences of a reform of the national science curriculum in Singapore. The distinctive feature of this reform was a shift towards a more enquiry-oriented pedagogy in the classroom. The study included 41 in-service teachers from five elementary schools (an additional 50 pre-service teachers were also part of the study). Data

collection included written questionnaire surveys, individual written narratives and teacher group discussions. Analysis of in-service teachers' written narratives showed that 'assessment conflict' was a common dilemma. This was elaborated in one teacher group discussion:

> This is our main concern – at the end of the day we need to deliver in terms of results. Because we have accountability in terms of results. I want very much to make lesson fun because that is what I believe in. But at the same time, at the end of the day, like [another teacher in the group] says, if they don't know how to answer process skill questions, or how to go about crafting their answers. My head's on a chopping board. (Kim et al., 2013, p. 303)

Kim et al. (2013) suggest that this tension between traditional high stakes testing practices, and more progressive enquiry-based pedagogies, could be a particularly strong dilemma within many Asian contexts in which the assessment system often has a major impact on students' future education and career choices.

A network of interacting factors

Several studies demonstrate that the factors in Table 2 are often strongly interdependent. In responding to externally driven reform teachers are constantly negotiating this network of factors, often experiencing personal dilemmas and tensions associated with potentially competing internal and external reform initiatives (e.g. Bantwini, 2010, Clark et al., 2011, Kim et al., 2013, Luttenberg et al., 2013, Roehrig et al., 2007, Saez and Carretero, 1998, Smith and Southerland, 2007, Melville, 2008), but also unexpected alignments between distinct factors (e.g. Olson, 1981, Ryder and Banner, 2013). For example, in an early study of eight teachers across three secondary schools enacting an integrated science project curriculum scheme in England, Olson (1981) describes some of the dilemmas teachers faced, and how these were resolved, over the three months of the research study. The integrated science project curriculum reform required teachers to engage in free ranging discussions in the classroom. However, teachers who personally supported this goal found that in practice such activities worked against other goals emphasised within their internal school environment such as 'getting students through an external examination and meeting parental, peer and administration expectations' (p. 265). Over time this dilemma was often resolved by a translation of external reform goals into trusted, familiar local practices, for example 'discussions became lectures or recitations; intellectual skill development was translated as content memorisation and examination rehearsal' (p. 265). Melville (2008) also provides examples of the significance of interactions between distinct curriculum policy reforms. In one case a teacher, Zoe, expresses frustration that she has had to abandon revisions made in response to a recently revised biology curriculum as a result of the cross-curricular Essential Learnings reform (p. 1192).

Whilst the emphasis within studies tends to be on the dilemmas and tensions faced by teachers in negotiating the network of interacting factors in Table 2, some studies identify (often unexpected) alignments that support teacher enactment of externally driven reform (Olson, 1981, Ryder and Banner, 2013). For example, Ryder and Banner (2013) report the experience of a secondary school teacher in England who was developing his use of formal classroom discussions in the context of socio-scientific issues such as climate change and genetic engineering. These student discussion activities were one feature of a statutory reform of the national science curriculum. Concurrent with this national curriculum reform his school was enacting a local internal reform across all subjects, involving a 'passport' of specific skills that included student debates and discussions. This alignment of external science curriculum and internal cross-subject curriculum policies supported this teacher in responding effectively to both reforms. Notably, in this example the coherence of these distinct reforms was unplanned. Elsewhere, there have been strong calls for a more planned systemic coherence of curriculum reform as experienced by schools at district (Roehrig et al., 2007) and national level (Oates, 2011).

Authority and Professionalism

A distinctive feature of this review is the explicit focus on teachers' experiences of externally driven curriculum reform. Given this external focus, particularly the criteria of *authority of adoption*, issues of teacher authority and professionalism are likely to feature strongly. Reflecting this internal-external framing, teacher professionalism has been conceptualised as 'boundary work' in which teachers are engaged over time in negotiating a range of cultural and political forces as they enact national and regional education policies in their local school contexts (Freidson, 2001, Seddon et al., 2013, Gewirtz et al., 2009). These perspectives emphasise teacher professionalism as a *process* rather than a fixed attribute; a *practice* that can vary for an individual teacher across teaching contexts and over time. Reporting on reform enactment within a science context, Donnelly and Jenkins (2001) define teacher professionalism as 'knowledge, responsibility and authority in relation to their work' (p. 167). This emphasises professionalism as a balance between accountability to external policy and teachers' more local authority over their activities in schools and classrooms. These issues of authority and professionalism surface in many of the 34 studies. Teachers in these studies often refer to tensions and dilemmas they experience as a result of an external requirement to respond to a significant curriculum reform that may run against their own professional beliefs and goals (Clark et al., 2011, Vos et al., 2011). In this section we focus on those (few) studies whose analytical focus is strongly on the processes through which science teachers balance and negotiate competing lines of authority, and associated perceptions of professionalism.

Teacher responses to external authority

Donnelly et al. (1996) examine the development and implementation of a curriculum strand focusing on investigative skills in science; part of a statutory reform of the national curriculum in England and Wales. The study involved interviews, typically on two occasions over a two year period, with 45 teachers across 19 secondary schools. Donnelly et al. provide 'a case study of the curricular, institutional and professional consequences of the centralised control of the curriculum' (p. 13). In many cases teachers were accepting of external control, at least of aspects of their work, e.g. the need for externally provided training in classroom activities associated with the reform. Indeed, many teachers were concerned that there was insufficient external guidance: 'you've been left to sink or swim' (p. 118); 'nobody tells us, you see, they say you've got to [use] your professional judgement' (p. 119). However, other teachers stated that the detail of the enactment of the reform was their responsibility: 'it's not something that somebody can tell you what to do, it is something you have to develop for yourself' (p. 120). Overall, the authors come to a striking conclusion:

> 'Teachers' comments largely ceded authority over the substance of their work in the classroom and laboratory, and the directions of its development, to others.' (Donnelly et al., 1996, p. 164)

They ascribe this to a mixture of teachers' 'diffidence' about their activities in response to the judgements of external 'experts', and 'acquiescence' that these experts have the right to reform teacher practices. The authors relate this to a broader theme of 'professional regression' in which those with influence tend to move away from the contexts of direct professional practice (p. 221).

Lunn and Solomon (2000) present case studies of four primary science teachers responding to a new statutory requirement to teach science within primary schools in England. Each teacher was interviewed on one occasion. Discussions included exploration of teachers' work and home biographies. A key claim arising from their analysis is that teachers' professional self-image is grounded in their 'science autobiographies', and that these personal reflective narratives are important factors in teachers' responses to external curriculum reform. Partly in contrast to the findings of Donnelly et al. (1996) all four teachers expressed frustration at their lack of autonomy in the face of what they saw as an overly prescriptive externally imposed science curriculum. This is most strikingly expressed by Florence: '[before the reform] if you were particularly interested in something I felt that I had the freedom to follow it up… I now feel I've lost that freedom' (p. 1050). In a study of Australian teachers' enactment of curriculum development materials in 'health and physical education' (featuring curriculum elements with a strong science content focus), Kirk and MacDonald (2001) describe teachers' ownership of curriculum change as being anchored in their 'authority to speak on curriculum matters in the local context of implementation' (p.

551). Thus, the teacher Florence is reflecting on her perceived loss of this local ownership of curriculum.

Mechanisms of external authority

Wallace (2012) provides a distinctive personal account of her experiences of enacting a biology curriculum in a secondary school in the US state of Georgia. This curriculum is characterised by Wallace as based on an 'authoritarian' and 'non-participatory' epistemology. The term 'epistemology' is used by Wallace to indicate a focus on what counts as student learning outcomes within curriculum documentation. For example, the detail of learning outcomes are presented from outside, with teachers (and students) having little if any role in constructing what counts as 'mastery' in the topic area. This form of curriculum results in Wallace's dissatisfaction as she finds it difficult to engage her students in meaningful enquiry activities in the classroom. This technically detailed, authoritarian curriculum worked against this teacher's personal professional goals. Wallace goes on to advocate a curriculum format where the nature of successful performance is more open-ended, citing the example of the national curriculum in New Zealand introduced around 2007. Such a curriculum presents teachers with more space to exercise their personal professional goals. Here then the form and language of the curriculum statements is one mechanism of external authority. Thus, different *genres of curriculum* can result in distinct professional experiences for teachers. This presents a mechanism through which a statutory (therefore highly authoritative in one sense) curriculum reform can be experienced as more or less authoritarian by teachers, depending on the form and language of the curriculum framework.

Wallace and Priestley (2011) provide another example of a science teacher experiencing an external reform as a positive 'professionalising' experience. They conducted five interviews and classroom observations with the secondary school science teacher Vanessa over a one year period. The reform context was a national reform in Scotland encouraging numeracy across the curriculum, and a regional reform to encourage use of assessment for learning strategies (following Black et al., 2003). Vanessa was positive about the goals of the assessment for learning reform from the start of the project. She worked within a network of 10-20 science teachers who met regularly over the year to co-develop classroom strategies in response to these, and other, external reforms. This Associated Schools Group was supported by a university researcher. Wallace and Priestley (2011) identify involvement in this school teacher network as a 'promoter of lasting change' in response to external reform. This teacher network supported teacher professionalism by providing resources (e.g. funding, university researcher support) and ongoing encouragement to engage in a range of development activities (e.g. formal action research, trialling different approaches to student peer assessment) but allowing teachers significant autonomy to adopt any of these to fit their interests and local contexts. Vanessa valued the fact that this activity was teacher-led and practice-driven, with the opportunity to meet and share developing practice

with other teachers. The outcome, at least for Vanessa, was positive and lasting change in response to an imposed external reform initiative.

Donnelly et al. (1996), introduced above, identifies external assessment as a key mechanism through which external agents exercise authority over the classroom activity of teachers (cf. Au, 2007). In all but one of the 19 schools involved in their study the pressure of external assessment was reported as the main motivation for changing classroom practice in response to the curriculum reform (p. 125). Schools were required to conduct standardised national tests in science, the outcomes for each school being made public. In some cases this pressure resulted in what many are likely to view as undesirable teaching/learning experiences, such as class chanting of assessment criteria. This is an example of (presumably) unintended consequences of external assessment pressures, as explored below. In her discussion of mechanisms of control, Wallace (2012) provides a striking teacher reflection, originating from an earlier study by Jeffrey and Woods (1998), of a UK primary teacher demonstrating how this mechanism of external authority can lead to teachers being 'forced' to act in ways that they themselves perceive as unprofessional:

> My first reaction was 'I'm not going to play the game', but I am and I know they know I am. I don't respect myself for it; my own self respect goes down. (Jeffrey & Woods, 1998, p. 160)

In a case study set in a high stakes testing regime in the state of Illinois, US, Zembylas (2004) refers to similar experiences reported by Catherine, a primary school science teacher. She is 'appalled by this obsession with testing! It kills inspiration and love for [science] learning, and it kills me too!' (p. 356). Significantly, Catherine experiences this testing obsession as both an externally driven policy, but also as an internal school culture of the 'good' teacher who teaches-to-the-test: 'I thought I was a lousy teacher for not doing what everyone else was doing [within my school]' (p. 356). She often found herself submitting to other teachers' goals, resulting in negative emotions in relation to her work. The case study goes on to relate how Catherine's experiences change when she moves to kindergarten teaching. Working with younger students, with a stronger expectation for 'hands-on' classroom approaches within the school, her perceptions of herself, and how she is viewed by her peers, improves. This case study, distinctive in its focus on the emotional experience of external reforms, demonstrates the significance of authoritative external and internal (school) discourses of the 'good' teacher for teachers' feelings of professionalism.

Mediators of external curriculum reform

Leander and Osborne (2008) present case studies of pairs of school teachers working in two primary schools in the US state of Illinois. Each teacher pair is introducing other teachers in their school to externally developed science curriculum materials. These case studies provide a distinctive perspective on authority and professionalism in teachers' responses to

external reform. These 'teacher-facilitator teams', employed within schools, act as mediators between the external curriculum reform and the internal school teaching community. The case studies reveal the significance of a range of actors in the process of responding to curriculum reform: teacher-facilitators, the teachers themselves, their teacher peers, students and parents (both real, and as imagined by teachers). The study focuses on how these teacher-facilitators 'position' themselves in relation to 'internal' peer teachers and 'external' curriculum developers. They occupy a precarious and problematic position; as insiders, with differing authoritative relations with other teachers in the school, and outsiders introducing an external curriculum reform. The study focuses less on the perspectives of the other teachers in each school. However, Leander and Osborne (2008) provide a basis for future studies that include consideration of the role of internal school 'mediators', or 'brokers' (Wenger, 1998), of external curriculum reform.

Teacher response as negotiating meaning

Several studies conduct an explicit analysis of teacher response to external curriculum reform as an extended process of learning or 'negotiating meaning'. For example, Fernandez et al. (2008) and Melville (2008) draw upon Wenger's socio-cultural analysis of communities of practice and his treatment of the processes of meaning making within these (Wenger, 1998). Bantwini (2010) refers to social constructivist perspectives on learning (Driver et al., 1994), placing the teacher in the position of a learner in the context of an 'inquiry-learning' response to external reform. Wallace and Priestley (2011) provide an analysis of teacher response in terms of Margaret Archer's critical realist social theory of change, with teacher response seen in terms of 'the dynamics of social change, showing the interplay between societal factors and individual factors, such as beliefs' (p. 361).

A distinctive contribution of these studies is to *conceptualise* the processes through which teachers make meaning of external curriculum reform within a school context. For example, Fernandez et al. (2008) provide an analysis of interviews with 10 teachers as they enact a statutory reform of the high school physics curriculum in New Zealand. This reform emphasised student investigations in the classroom and the inclusion of socio-scientific issues. The study draws upon Wenger's conceptualisation of meaning making within communities of practice (Wenger, 1998). Wenger conceptualises meaning making as a duality involving two interacting processes: reification and participation. Fernandez et al. (2008) identify the New Zealand curriculum document as a reification of the intended meanings of curriculum designers. Following Wenger they identify this text as 'the tip of the iceberg' of the meaning making process. Within a school context teachers are involved in an ongoing process of participation in relation to the curriculum document. Following the duality of meaning making this process involves further reification of curriculum meanings, for example through local school or classroom specific texts such as schemes of work, worksheets and student assessment items. Fernandez et al. (2008) show that the teachers

in their study are often making meaning in the absence of key mechanisms of community participation. For example, many of the schools have only one physics teacher, resulting in little if any opportunity for meaning making through participation within physics teacher communities. Furthermore, in the absence of significant professional development activity the teachers have little participation with those within the external (to the school) communities involved in developing the curriculum reform. The result is often an enactment of the reform reflecting meanings quite distant from those intended by curriculum developers.

Luttenberg et al. (2013) present four 'forms of search for meaning' that are then used to analyse four teachers' reflections of their experiences of 14 years of curriculum reform in the Netherlands. The authors' aim is to move beyond a conceptualisation of teacher response as either agreement or resistance, to a more nuanced and 'process' characterisation of response. Each of the four forms are attempts by teachers to 'construct a workable relationship' with external reform, as they seek a balance between continuity and change. *Assimilation* involves a teacher transforming curriculum ideas to match his/her existing ways of thinking and practice. Through *accommodation* a teacher transforms his/her beliefs and practices to match those perceived within the reform. *Toleration* involves a teacher accepting aspects of an external reform even though these may be in tension with personal perspectives on teaching and learning, resulting in a coexistence of distinct perspectives. Finally, *distantiation* is the rejection of external reform and the continuation of existing practices and beliefs. One of the teachers in this study, Bart, is a science teacher. The analysis of Bart's reflections shows that he follows several of these 'forms of search for meaning' at different times, depending on the nature of the reform (these reforms are characterised as either: emergent and local; national; or standardised) and his local school context and personal career goals. This typology of forms of response, and the incorporation of several of these into accounts of individual teacher's responses to external curriculum reform, demonstrates an analysis of teacher response as an ongoing process of meaning making.

Discussion

This literature review addresses the question: 'what do we know from research studies about the experiences and reflections of teachers in the enactment of externally driven school science curriculum reform?' Findings from the studies have been examined across three themes: the range of factors influencing teacher response; issues of authority and professionalism; teacher response as 'meaning making'. This discussion draws upon these themes to make recommendations for the focus, design and conceptualisation of future research studies. It finishes with recommendations on how future curriculum policy development and enactment can recognise and support the professionalism of science teachers.

Recommendations for future research studies

Given the significance for school science education it is striking how few studies have examined the detail of 'everyday' teachers' experiences of externally driven science curriculum reform. Rather, many research studies tend to focus on the experiences of teachers distinctively positioned in the reform process. These teachers are often 'internal' to the reform, selected by university-based curriculum developers, and commonly have a favourable perspective on the reform. Of course such studies (often-termed 'efficacy studies') are important in showing how a favourable and committed enactment of a curriculum reform might impact on student experiences and learning. However, fewer studies consider the detail of teacher experiences of, and reflections on, curriculum reform initiatives in a broader range of school contexts[1]. The stage model of educational innovation developed by the Institute of Educational Sciences in the US does emphasise the importance of examining teachers' 'fidelity of implementation' of a reform across an increasingly broad set of school contexts (Lee and Krajcik, 2012), thus focusing on teachers' classroom *activities*. However, this review has highlighted the need for more attention to be given to these teachers' *experiences* and *reflections* working in specific educational contexts *over time*. Such studies conceptualise reform enactment as an inevitable process of adapting to local contexts, rather than implementing a curriculum reform 'as intended' by curriculum developers (as signalled by the term 'fidelity of implementation'). Similarly, following terminology in Leach et al. (2006), future studies should include more consideration of the experiences of 'transfer teachers' (i.e. those not involved with reform development) alongside analyses of the work of 'development teachers'.

One approach to supporting the development of such research studies is to make them an integral part of all curriculum development programmes. There is a significant investment of time and resources in science curriculum development programmes worldwide. However, it is striking how few of these programmes include a significant research component. For example, in the US since the 1980s the NSF has funded many large-scale curriculum development programmes within its Systemic Initiatives, often including significant professional development activities (Kahle, 2007, Lawrenz and Desjardins, 2012, Huffman and Lawrenz, 2004). However, in her review Kahle states that little research on these Systemic Initiatives has been published (p928)[2]. Although many of these NSF programmes included substantial evaluation activities, these were often conducted by state departments of education or private groups, typically outside of universities. Lawrenz and Desjardins (2012) support Kahle's claims, adding that many evaluations of large-scale curriculum development initiatives in the US did not demonstrate rigorous procedures, for example often using convenience sampling techniques. These evaluations also tend to be summative

[1] Indeed, given that 73% of the studies identified for this review are set within US and European schooling contexts, future studies could usefully draw upon a broader range of distinctive school settings worldwide.
[2] Some exceptions, with a strong focus on external teachers' experiences, are included in this review (e.g. Roehrig et al., 2007, Penuel et al., 2009).

rather than formative. Furthermore, the focus of evaluations was often largely on student learning outcomes, and did not include significant analysis of teacher experiences (e.g. Rivet and Krajcik, 2004). This sole focus on student learning outcomes appears to be a mistake we are in danger of repeating with much current emphasis on Randomised Control Trial (RCT) evaluations of curriculum developments (Rudolph, 2014). Of course, examining student learning outcomes is of central importance in evaluating the impact of curriculum reforms. However, to support effective, equitable and sustainable 'scale up' of curriculum reforms it is also important to develop a detailed understanding of the differing responses of teachers working in diverse school settings (Lynch et al., 2012, Penuel and Fishman, 2012). Overall, many previous large-scale curriculum development programmes represent a missed opportunity for research into how teachers outside of these reforms experience, and reflect on, these reforms in their local contexts. Without such insights, significant system-wide scale-up of these curriculum development activities, a core goal of such programmes, is unlikely to succeed.

A further outcome of this review is to highlight the differing ways in which teachers' responses to curriculum reform have been conceptualised. Here two recommendations are made for the conceptualisation of teachers' responses to curriculum reform, each with implications for study methodology and design. Firstly, the *timescale* considered for teacher response needs to be extended to more long-term analyses of the development of teachers' responses. Secondly, the *framing* of this response needs to expand beyond an individual response driven by personal knowledge, skills and beliefs, to more holistic, systemic perspectives that emphasise teacher working practices within teacher groups often influenced by broader systemic policy structures. These two recommendations are developed below.

This review highlights the extended timescale of teachers' responses to external curriculum reform. Several of the studies show that teachers demonstrate often very significant shifts in their enactment of external reforms many years after they are introduced (Bantwini, 2010, Hanley et al., 2007). For example, the longitudinal study of reform enactment in England by Ryder and Banner (2013) identifies many teachers who are still making significant changes in their teaching of specific curriculum reform elements 3-5 years after official implementation of the reform. Short timescale studies that demonstrate teachers' 'rejection' of a reform, or more typically their adaptation of the reform to suit local contexts, will miss these longer timescale shifts in teacher responses. Future research studies need to conceptualise teacher response as an extended process over time, utilising longitudinal designs to explore this process of enactment.

Given the range of factors represented within Table 2, and the likelihood that the form and prevalence of these factors shift over time, conceptualisations of teacher response to external curriculum reform should reflect a broad framing in terms of personal, internal and

external factors. In responding to a science curriculum reform teachers are influenced by personal beliefs and knowledge, but also internal features of their school workplace (students, teacher peers, school management) and contexts external to the school (district, state, national educational policies; parental pressures, high stakes testing, school/teacher accountability measures). This review demonstrates that studies following such a perspective capture more of the range of contextual influences on teachers' work, and provide a more holistic account of the teachers' experience. In particular, these studies often provide an account of the reasons why many teachers do not enact a curriculum reform as intended by developers, revealing that in many cases teachers have sound professional justifications for such a response. Such an interpretation counters the deficit view that a 'failed' curriculum reform is *necessarily* the result of insufficient teacher knowledge and/or skills concerning the reform. This holistic framing perspective reflects many conceptualisations of school teachers' activity, drawing from studies in other curriculum areas and indeed beyond curriculum reform (Cobb et al., 2003, Spillane, 1999). Such conceptualisations emphasise, for example, that teachers do not act as technicians taking a pre-formed policy and 'putting it into practice'. Rather policy is enacted and created within specific school workplaces, with teachers working as crucial and inevitable 'co-constructors' of policy (Ball et al., 2011).

This holistic framing of teacher response should not be seen as downplaying the central role of the individual teacher in curriculum reform. The work of the social theorist Margaret Archer is helpful here. Her social realist account of human activity explores the processes through which the human agent acts within social structures (Archer, 2000). She explores a middle ground between reductionist accounts of human agency that focus on individual rational choice, and anti-humanist accounts that privilege social structures as deterministic of human behaviour:

> 'How the world is *constrains* our language about reality, and especially of how direct (that is socially unmediated) contact with the world shapes our languages, so that they are not just about the human communities to which we belong'. (Archer, 2000, p. 49)

Archer's social realist perspective highlights in particular the personal 'concerns' that individuals have, and how these can develop into personal career 'projects'. These concerns and projects however are constituted within the 'constraints and enablements' of the individual's social world (Archer, 2003). Thus, in the context of teachers' responses to external curriculum reform, these personal concerns and career projects are central and may carry significant personal investment for teachers. However they are not independent of the structures of their social world (e.g. personal and career biographies, relationships with peer teachers, expressions of local school priorities, media portrayals of the 'good' teacher) and indeed are partly constituted by them.

Recommendations for the process of curriculum policy development and enactment

Earlier it was argued that the outcomes of school science education are often linked directly with national economic progress, in common with mathematics education and language skills. The political importance of national economic progress results in many stakeholders beyond education holding a strong stake in science education outcomes. In many countries this has resulted in the inclusion of science within very visible and powerful accountability measures, e.g. high stakes national or regional testing of student attainment, and publication of national 'league tables' of school performance. Several studies in this review have reported on the impact of such accountability measures on the responses of science teachers to external curriculum reform (Benson, 1989, Donnelly et al., 1996, Hughes, 2000, Kim et al., 2013, Olson, 1981, Wallace, 2012, Zembylas, 2004). The message from these studies is that policy makers who advocate such accountability measures need to consider carefully the ways in which these are likely to influence the detail of teachers' classroom activity. As shown by Kim et al. (2013), Donnelly et al. (1996) and Zembylas (2004) in particular, the key mechanism of influence in such systems is external assessment; there is pressure on teachers to 'teach to the test'. This mechanism of authority needs to be developed as a positive lever to support the detail of reform enactment. For example, curriculum reforms, such as the introduction of socio-scientific issues and associated ethical debates, need to include robust assessment items in these curriculum areas suitable for the full student attainment range. This is particularly important within school systems with high stakes accountability mechanisms based on student attainment on external examinations.

Changes to the science curriculum have often involved significant shifts in the focus and form of curriculum content. The studies in this review include shifts towards context-based science teaching, teaching about ethical issues in the context of socio-scientific issues and teaching about the history and philosophy of science. Such shifts often take teachers some distance from their formal area of subject expertise: canonical science knowledge. The studies show that some teachers have been strongly challenged by what they see as an unjustified attack on the nature of their subject. For example, the middle school teacher Shelley resisted an imposed curriculum shift towards values and attitudes, preferring to continue her emphasis on teaching what she saw as the most important curriculum elements: fact acquisition, vocabulary and definitions (Cronin-Jones, 1991). Furthermore, such shifts can be experienced as challenges to teachers' professional identities (Kirk and MacDonald, 2001, Leander and Osborne, 2008, Ryder and Banner, 2013). These research findings have important consequences for curriculum development and enactment policy. Significant shifts in the science curriculum have major implications for the working lives of teachers. As a result, the timescale of their response anticipated by policy makers, e.g. in designing a piloting of the reform, needs to be considered in terms of years rather than

months. Furthermore, policy makers need to provide significant and ongoing opportunities for teachers and curriculum reformers to engage critically in mutual reflection on the purposes of science education, and therefore what counts as legitimate curriculum content. Significantly, if teachers' personal goals, beliefs, identities and local school contexts are to be engaged with appropriately, this needs to be a *mutual reflection*, rather than a professional development activity in which curriculum reformers seek to 'develop' the views of practising teachers.

This review has also highlighted policy levers that can support, or constrain, teacher professionalism. Drawing from the definition introduced earlier professional teachers: have *expertise* in their subject and its teaching and are responsible for the further development of this expertise; are responsible for the outcomes of their work, for example in terms of student learning, and are held externally *accountable* for these outcomes; and exercise *authority* over the detail of their work in the classroom (Donnelly and Jenkins, 2001). In the specific contexts of external curriculum reform considered here, these elements of teacher professionalism highlight the need to achieve an appropriate balance between, on the one hand, 'following' external curriculum requirements and being led by associated accountability measures, and, on the other, exercising teacher authority over the detail of external reform enactment within the classroom. It is possible to get this balance wrong. Donnelly et al. (1996) provide striking examples of teachers 'ceding authority' over their work to perceived external experts. Furthermore, this and other studies in this review show how inappropriate accountability mechanisms can constrain teachers' practice, often working against teachers' judgments of good teaching. Following the definition above, such curriculum reform contexts do not promote the professionalisation of teaching. Indeed, referring to educational policy more broadly, Ball has called attention to 'the terrors of performativity', in which an overly constraining and prescriptive accountability mechanism can lead to a de-professionalisation of teaching (Ball, 2003).

However, other studies in this review suggest that a more fruitful balance between external accountability and local authority can be achieved within appropriately constructed curriculum reform policy contexts. In the introduction to their study Squire et al. (2003) highlight the role of 'flexibly adaptive curricula'; external curriculum reforms with mandatory core themes but sufficient flexibility to be adapted to local contexts. For example, the science teacher Vanessa drew upon the core theme of 'assessment for learning' from an external reform, but enacted this in particular ways in her local context (Wallace and Priestley, 2011). Crucially, Vanessa was positioned explicitly by curriculum developers as having responsibility for the local detail of enactment. This reform context provided Vanessa with: autonomy over local practices; extended time to develop reform implementation; ongoing participation within an inter-school teacher community; and support from experts associated with the reform (i.e. 'brokers' of the reform). Relatedly, it is striking that Penuel et al. (2009) found that extended time for local planning of enactment, rather than externally provided professional development activities, had the most impact on

teachers' perceptions of the curriculum and its implementation. Similarly, drawing from Wallace (2012), it is likely that the *genre* of curriculum texts also impacts on teacher professionalism. Wallace shows that technically detailed, authoritative curricula texts can work against teacher professionalism, and suggests that more open curriculum standards can be experienced by teachers as externally guiding, yet also locally empowering.

Conclusion

The enactment of external curriculum reform in school science has significant implications for policy makers, teachers and students. This review has highlighted the need for stakeholders in curriculum reform to ensure a broad understanding of teacher and school response to such reforms, recognising: the necessarily extended timescale of this response; the role of factors personal to the teacher and how these interact with internal school factors; interactions with broader systemic reform initiatives and structures, often beyond science; the significant impact of teachers working within groups to make meaning of reform in local contexts; and the ways in which external curriculum reform can impact on teacher professionalism. The review has identified mechanisms that can support the effective enactment of external curriculum reform in local contexts. These mechanisms include appropriate 'genres' of curriculum framework, coherence between distinct local and systemic policies experienced by teachers, and support for inter-school teacher communities charged with local implementation. The professional teacher should be both accountable to external policy but also expected to exercise authority over the detail of their practice in response to external curriculum reforms. The recognition, and appropriate use, of such policy processes can provide an effective balance between external accountability and local autonomy; one that supports rather than constrains teacher professionalism.

Acknowledgements

The author thanks three anonymous reviewers for their helpful comments on the original manuscript. Special thanks to Jim Donnelly for undertaking the role of journal Editor for this submission.

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	Curriculum Reform Notes	Country	Age range[3] P/S/UpS	Research Methods
Bantwini (2010)	National science curriculum revised in 2002. Content is specified, but not at grade level. Commitment to pedagogy of outcomes-based education (OBE): 'achievement-oriented, activity-based and learner-centred' (p85).	South Africa	P	Questionnaire (88 responses) followed by interviews with 14 teachers.
Benson (1989)	Government curriculum guide on the topic of nutrition. Involves teaching/learning of conflicting explanations of nutrition addressing epistemology of science (p331).	Canada	S	Audio-recorded lessons, and interviews over four weeks with three teachers in one school.
Bryce & Gray (2004)	New qualification addressing social and ethical issues around biotechnological progress (p717).	Scotland	UpS	Interviews with 10 teachers.
Clark et al. (2011)	New curriculum topic Chemical Systems (p273) with an emphasis on scientific literacy (Vision II) (Roberts, 1988).	South Africa	S	Written retrospective narratives by two teachers.
Cotton (2006)	Qualification including the requirement to teach controversial environmental issues (p70).	England	UpS	Series of interviews with three geography teachers over two years.
Cronin-Jones (1991)	University-designed 20-lesson curriculum package on wildlife conservation. Curriculum reform focus: 'several levels of knowledge as well as problem-solving skills and values and attitudes' (p237).	US	P/S[4]	Two teachers. Researcher field notes and interviews over a six week period.
Donnelly et al. (1996)	Introduction of an 'investigative skills' strand in the national curriculum for science.	England	S	Interviews with 45 teachers in 19 schools over a two year period.
Fernandez et al. (2008)	New national curriculum for physics emphasising student investigations in the classroom, real world contexts, student-centred pedagogy and inclusion of science-technology-society issues (p194).	New Zealand	S	Interviews with 10 teachers.
Hanley et al. (2007)	New qualification for 14-16 year olds: Twenty First Century Science. Includes emphasis on 'ideas-about-science' addressing the goals of scientific literacy: data and its limitations; correlation and cause; theories; the scientific community; risk;	England	S	Classroom observations and interviews with 12 teachers across nine schools.

[3] Primary to age 11 years. Secondary 11-16. Upper Secondary 16-18.
[4] Middle School setting. Teachers working with fifth and sixth grade students.

	making decisions about science and technology (p1).			
Hughes (2000)	Salters' Advanced-Level Chemistry qualification emphasising science knowledge within social contexts, e.g. chemistry and air pollution. Related to goals of science-technology-society (STS) movement (p426-429).	England	UpS	Classroom observations and interviews with two teachers over nine months. Course documentation also examined.
Kelly & Staver (2005)	Discovery Works: a 'hands-on, activity-based' science program (p32). Consists of 'text-based units that are supported by kits of materials' (p33).	US	P	Questionnaires (175), interviews (14) and researcher field notes within a district of 13 elementary schools.
Kim et al. (2013)	New science national curriculum in Singapore, emphasising a shift towards a more 'inquiry-oriented pedagogy' (p292).	Singapore	P	41 teachers from five schools. Questionnaires, individual written narratives and teacher group discussions.
Kirk & MacDonald (2001)	New curriculum specifications in 'health and physical education' within two states. Science-related topics include people and food, human health, and populations (p555-557).	Australia	S	Teacher interviews (characteristics and numbers unclear).
Larkin et al. (2009)	Integrate Science Program (ISP). Ten detailed teaching units emphasising 'science processes, the unity of science, the nature of science, science skills, and the development of reasoning' (p814).	US	S	Series of interviews with six teachers in one school.
Leander & Osborne (2008)	Developing 'activity-centred and inter-disciplined science curriculum and teaching practices' (p27) in response to 'state and local expectations around content and standards (…) [and] teacher-articulated goals about how science should be taught – as hands-on inquiry' (p24).	US	P	Case studies of two teacher pairs. Classroom observations, interviews, informal conversations, observations of teacher meetings.
Lunn & Solomon (2000)	National curriculum for science introducing a specification of science content (new at this level) and a requirement for practical work (p1044).	England	P	Single interviews with seven teachers; detailed case studies presented for four of these teachers.
Luttenberg et al. (2013)	A retrospective analysis of three phases of curriculum reform over 14 years: emergent and local; national curriculum; local inter-school standardisation of curriculum (p9-10).	Netherlands	S	Two interviews with a chemistry teacher over one year (three non-science teachers were also part of the study).

Melville (2008)	Cross-curricular Essential Learnings state-wide curriculum framework emphasising: thinking, communicating, personal futures, social responsibility and world futures (p1188).	Australia	S	Audio recordings of regular school science department meetings over a two year period, supplemented by school documents.
Melville et al. (2011)	Teaching of science through enquiry (p2275).	Canada	S	Three interviews with each of two teachers.
Miller et al. (2010)	Specification of 'outcomes-based unit descriptors' within a life sciences qualification (p226).	Scotland	UpS	Sequence of interviews and classroom observations involving three life sciences teachers over one term (part of a larger study).
Mitchener & Anderson (1989)	'Topics in Applied Science', science-technology-society (STS) curriculum (p352-354).	US	S	14 teachers across two schools over six months. Classroom observations, interviews, teacher documents.
Olson (1981)	Schools Council Integrated Science Project (SCISP). Included specification of 'goals' (e.g. habits of critical intelligence), 'social relationships' (e.g. teacher-teacher cooperation), and 'technology' (e.g. science as a process) (p263).	England	S	Eight teachers across three secondary schools. Each teacher interviewed four times over a three month period.
Penuel et al. (2009)	National Science Foundation (NSF) funded curriculum package: GLOBE. Provides curriculum materials and an online database for the teaching of earth sciences for students up to eighth grade (p662-664).	US	P	Questionnaire responses from 225 teachers across 51 schools.
Rigano & Ritchie (2003)	State-wide syllabus encouraging 'student-centred learning' and 'constructivism' (p299).	Australia	S	Classroom observations and interviews with one teacher.
Roehrig et al. (2007)	NSF-funded Living by Chemistry curriculum package, characterised by real-world contexts and learning by enquiry (the '5E inquiry model') (p887).	US	S	27 teachers across 12 schools, within a 15-school district. Each teacher observed 6-8 times over one year, with a terminal interview.
Ryder & Banner (2013)	National curriculum for science emphasising the teaching of socio-scientific issues and the nature of science, alongside canonical science knowledge (p493).	England	S	22 teachers from 19 schools. Each teacher interviewed once per year over three years.

Saez & Carretero (1998)	Integrated science: 'more practical work based on constructivist learning theory' (p719).	Spain	S	Interviews with six teachers over one year.
Smith & Southerland (2007)	'Reform tools designed to change science teachers' thinking about science and science instruction (national science standards, state-mandated science curricula, and associated criterion-referenced testing)' (p401).	US	P	Two teachers. Initial questionnaires followed by classroom observations and interviews over eight months.
Squire et al. (2003)	ActiveInk Air Quality module. A project/enquiry-based, technology-rich environmental science curriculum unit (p475-477). Includes use of an e-learning portal.	US	S[5]	Four teachers. Classroom observations, pre and post-lesson interviews, documentation analysis.
Teo (2012)	Enquiry-based Advanced Chemistry qualification (p661).	US	UpS	Classroom observations and interviews with one 'focus teacher' over a year. Additional interviews with others associated with this teacher.
Vos et al. (2010)	Chemie im Kontext teaching materials emphasising context-based teaching (p1415-1416).	Germany	S	Four teachers. Documentation, classroom observations and interviews.
Wallace (2012)	Outcome-based 'authoritarian' curriculum standards (p295, 300).	US	S	Personal account of author's experiences as a school teacher.
Wallace & Priestley (2011).	National reform context encouraging numeracy across the curriculum, and a regional reform encouraging use of assessment for learning strategies (p368).	Scotland	S	One science teacher within a broader study. Five interviews and classroom observations over a year.
Zembylas (2004)	Teaching science within a high stakes testing regime.	US	P	One teacher. Documentation, classroom observations and interviews over three years.

Table 1 Summary of curriculum reform context and research methods for studies included in review

[5] Includes two high school teachers, one middle school teacher and a university teacher.

PERSONAL (TEACHER FOCUS)
Personal factors relate to a teacher's: P1. subject knowledge; P2. pedagogical skills; P3. beliefs about the purposes of science education; P4. views about the epistemology of science; P5. beliefs about how students learn and his/her role in the classroom; P6. beliefs about the intentions of the curriculum reform; P7. perceived audiences for his/her work; P8. professional and personal biography; P9. professional identity.
INTERNAL (SCHOOL FOCUS)
I1. Students' differing backgrounds and aspirations I2. Students' interpretations of what counts as appropriate science curriculum content I3. Parental aspirations and their visibility to teachers I4. Availability of teaching resources (e.g. textbooks, practical activities) I5. Physical teaching spaces (e.g. laboratory provision) I6. Engagement of teachers in professional development activities I7. Science department working practices (e.g. collegial, fragmented) I8. School and departmental leadership style I9. What counts as appropriate assessment of student learning I10. Local cultural perceptions of the 'good', 'professional' teacher I11. School ethos and priorities I12. Relation of the science curriculum reform to other reforms in the school I13. Role of inter-school mediators/brokers of reform
EXTERNAL (SYSTEMIC FOCUS)
E1. Flexible versus prescriptive national/regional curriculum frameworks E2. Participation in ongoing, inter-school teacher networks E3. Other national/regional education reform agendas E4. Accountability measures (e.g. through external measures of student attainment, school league tables, school inspectorate policies) E5. Specifications for externally awarded science qualifications.

Table 2 Factors influencing teacher response to externally driven curriculum reform