Is curricular incoherence slowing down the pace of school mathematics in South Africa? A methodology for assessing coherence in the implemented curriculum and some implications for teacher education

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Abstract

A dominant explanation in large-scale mathematics and science studies is that opportunity to learn (OTL), defined as the curriculum actually made available to learners in the classroom, has a powerful effect on learner achievement. Measures for establishing descriptions of students' opportunity to learn identifiable in the literature include the notion of 'curricular coherence'. Research suggests learners learn mathematics more readily if topics and sub-topics are presented to them in ways that are conceptually connected over the school year/s. This article offers an emerging methodology for collecting and analysing data, across multiple classrooms, on the order in which teachers cover mathematics topics over one academic school year. The methodology outlined in the article was developed to assess within grade curricular coherence in 38 grade 6 mathematics classrooms across a sample of 24 randomly selected schools serving low income communities in the Cape Peninsula of the Western Cape Province, South Africa. The analysis of data on the sequencing of curricular content over the school year showed that, when the sample of teachers exercised their own judgment in deciding on the order in which to cover mathematics content across the school year, most teachers did not present learners with a coherent programme of learning 'in the disciplinary sense' (Schmidt,Wang and McKnight, 2005). The article considers some implications for mathematics teacher education and professional development.

Curricular coherence as a dimension of opportunity to learn

Large-scale cross-national and national studies have shown a positive association between opportunity to learn and learner achievement (Rosenshine and Berliner, 1978; Berliner, 1978; Heyneman and Loxley, 1983; Brophy and

Good, 1986; Smith, Smith and Bryk, 1998; Reynolds and Creemers, 1990; Wang, 1998; Schmidt, McKnight, Houang, Wang, Wiley, Cogan and Wolfe, 2001; Porter and Smithson, 2001; Reynolds, Creemers, Stringfield, Teddlie, and Schaffer, 2002; Schmidt, Houang and Cogan, 2002; Rowan, Correnti and Miller, 2002; Hiebert and Grouws, 2007; Gillies and Quijada, 2008; Carnoy, Chisholm *et al.*, 2011a). Measures for establishing descriptions of learners' opportunity to learn the curriculum include '*content coverage*', defined as learners' exposure to the content that is expected to be learned; '*content exposure*', defined as the amount of time spent on the curriculum contents; and '*curricular pacing*', defined as the pace at which learners progress through the curriculum within and across successive grades. These dimensions of opportunity to learn (OTL) are associated in the literature with helping to ensure that learners have the pre-requisite content knowledge for the next year of schooling and preventing a cumulative deficit in subject knowledge (Smith *et al.*, 1998).

Some studies (for example, Carroll, 1963; Schmidt, Jorde, Cogan, Barrier, Gonzalo, Moser, Shimizu, Sawada, Valverde, McKnight, Prawat, Wiley, Raizen and Britton , 1996; Stevens, 1996; Schmidt *et al*, 2002; Schmidt *et al*, 2005) also stress the importance for student learning of '*curricular coherence*', defined in the literature as the extent to which curriculum topics and sub-topics are logically connected as they are introduced and presented to learners within lessons, within each grade year, and across different grades. For example, Schmidt *et al.* (1996) in their investigation of mathematics and science teaching in six of the countries that participated in the Third International Mathematics and Science Study (TIMSS), considered the coherence with which topics or sub-topics were developed and sequenced both within and across lessons.

South Africa's recently drafted *Curriculum and Assessment Policy Statements* (CAPS) for mathematics (DoBE, 2011) (to be implemented from 2012) provide teachers with sequenced mathematics content topics to be taught in each term. While a criticism of this move is that this level of specificity undermines teachers' professional autonomy, we do not have much hard data in the South African context, about what happens when teachers exercise their own judgment in deciding on the order in which to cover mathematics content across the school year. There is also a dearth of research on the within grade curricular coherence dimension of learners' opportunity to learn in practice in South Africa.

This article examines the sequencing of teachers' coverage of mathematics topics over a single academic school year at a time when there was no specification in official curriculum documents and teachers were expected to exercise their own judgment. According to Posner and Strike (1976)

> Content sequences are part of the overall *content structure*. *Content structure* refers to the content elements and the ordering relationships that exist between them. . . Most questions about content structure can be reduced to questions concerning what content comes before what other content and the rationale for that order (i.e. *the sequencing principle,* or more precisely, the *ordering relations*) (p.666, authors' italics).

In this article, the term 'curricular coherence' refers to "the degree to which domain-specific or disciplinary content is systematically presented to learners in terms of the conceptual coherence of its organization" (Reeves and Muller, 2005, p.107). In the next section we explain why we use a conception of curricular coherence that draws on the notion of curricular coherence as adherence to the underlying structure in a discipline (Posner and Strike, 1976; Schmidt *et al.*, 2005).

Curricular coherence in the disciplinary sense

According to Schmidt *et al.* (2005, p.529) a teacher's ordering of curriculum topics is coherent if it is articulated "as a sequence of topics and performances consistent with the logical and, if appropriate, hierarchical nature of the disciplinary content from which the subject-matter derives". In other words, these and other researchers assert that the sequencing or ordering of topic coverage in a school subject should be "logically consistent" with the nature of the foundational discipline, and "reflect the inherent structure of the discipline" (Schmidt *et al.*, 2005, p.528).

The theoretical work of the British sociologist, Basil Bernstein draws attention to the nature of subject-specific discourses, "the internal principles of their construction and their social base" (Bernstein, 2000, p.155). In his theorisation of forms of knowledge and knowledge structure, Bernstein (1999, 2000) distinguishes, firstly, between horizontal discourses (everyday or common sense knowledge) and vertical discourses (academic knowledge). In Bernstein's theorisation, the discourse of the academic domain mathematics has to be re-contextualised or re-interpreted as the school subject, mathematics. It is this re-contextualisation which codifies and separates or creates a boundary between curricular school knowledge and non-codified everyday knowledge. However, not all specialised academic knowledge structures take the same form.

Bernstein (1999; 2000) distinguishes between two forms of knowledge structures within academic discourses. Some specialised knowledge structures, as in the sciences, are hierarchically organised in terms of principles of ‘conceptual coherence’ so that each level of meaning is conceptually related to the next level (Review Committee, 2000 in Muller, 2001). Other specialised knowledge structures, as in the social sciences, are organised around principles of ‘connective coherence’ (Muller, 2001) and take the form of a ‘horizontal’ series of specialised language . Vertical discourses also vary in terms of the strength of their grammars or conceptual syntax.

Curricular coherence in the field of school mathematics

The school subject mathematics is, in Bernstein’s terms, a ‘singular’ which draws on a relatively vertical knowledge structure with a strong conceptual grammar. It is these features that make it relatively easier to explicate the conceptual ordering of curricular knowledge across various grades for the school subject mathematics than it is for some other school subjects such as art (Muller, 2007).

Schmidt *et al.* (2005, p.529) demonstrate how a lack of curricular coherence in school mathematics is evident in the disruption of the “hierarchical aspects of the discipline” when topics are not sequenced to reflect the logical structure of the foundational discipline. They show how such a lack of coherence can reveal itself through “the introduction of a topic before the pre-requisite knowledge that makes a reasonable understanding of the topic possible” (Schmidt *et al.*, 2005, p.529). Examples of forms of ‘curricular incoherence’ in mathematics that these authors provide include: the “placing the coverage of percentage before the coverage of common fractions” (Schmidt *et al.*, 2005, p.529); or “coverage of the properties of whole numbers (such as the commutative and distributive properties) at 1st grade, at the same time as they are beginning to study the basic operations” (Schmidt *et al.*, 2005, pp.541–2). However, as Schmidt *et al.* (2005) and Muller (2007) point out, some curriculum topics are not explicitly hierarchical, even in mathematics. Some content topics are developed through repeated exposure at different times. In other words, the same mathematics topic may remain in the curriculum and be covered at fairly elementary levels that evolve into different levels of complexity or deeper levels of understanding over time (Bruner, 1960). They may receive attention at different times over the school year, or at different grade levels. Other mathematics topics provide reference points or forms of continuity that support or ‘buttress’ the overall coherence of the curriculum, both within a grade and across grades. For these and other reasons the structure of the overall school mathematics curriculum, or a programme of learning over a single school year, “even in an area that is largely hierarchical”, ideally takes the form of ‘a web’ or network, “in which the inter-connections become a critical part of the hierarchical structure” (Schmidt *et al.*, 2005, p.528).

Curricular coherence and student learning

In their analysis of data on the official curricula of countries participating in the TIMSS, Schmidt *et al.* (2002, 2005) found that curriculum topics in the countries that performed the highest in the TIMSS standardised tests are “sequenced to reflect the structures of the disciplines” (Schmidt *et al.*, 2005, p.556) of mathematics and science. In other words, these researchers show that a feature of the official mathematics and science curricula in the highest performing countries is that they articulate the logical and hierarchical nature of the disciplinary content from which they are derived. These authors acknowledge that it is not possible to demonstrate causality in relation to student learning and this ‘sequencing principle’ (Posner and Strike, 1976), given the kind of survey data the TIMSS collected. Nevertheless, they believe that their analysis of the TIMSS curriculum data from high performing countries strongly supports the view that this form of curricular coherence “results in greater learning and deeper understanding” (Schmidt *et al.*, 2005, p.556).

According to Schmidt *et al.* (2002, p.19)

> …“to be coherent”, a set of content standards must evolve from particulars (e.g. the meaning and operations of whole numbers, including simple maths facts and routine computational procedures associated with whole numbers and fractions) to deeper structures inherent in the discipline. This deeper structure then serves as a means for connecting the particulars (such as understanding of the rational number system and its properties). The evolution from particulars to deeper structures should occur over the school year within a particular grade and as the student progresses across grades.

Schmidt *et al.* (2005, p.554) further argue that, for learners to “move beyond its particulars”, “at some level” the structure of the discipline has to become visible to them. They assert that the absence of a clear pattern of subject-matter coherence, which emerges out of *ad hoc* topic sequencing, hampers or slows down learning because learners experience the curriculum as a series of fragmented and seemingly unrelated components where the parts are disconnected from the whole. Schmidt *et al.* (2005, p.554) aver that, when "the inherent logical structure of the discipline" is made "more visible both to teachers and students", the pace of learning is accelerated. However, this does not imply that there is one single 'best' sequence.

The link between curricular coherence in the intended and enacted curriculum, and increases in curricular pacing in content coverage is echoed by other researchers. For example, as far back as 1963, John Carroll (1963, p.726–7) suggested that "if the quality of instruction is anything less than optimal, it is possible that the student will need more time to learn the task than he (sic) would otherwise need." One of the factors in Carroll's model of school learning that affect learner achievement includes the organisation and presentation of content "to be learned in such a way that the student can learn it as rapidly and as efficiently as he (sic) is able" (Carroll, 1963, p.726). In an investigation of opportunity-to-learn in Chicago public schools, the Consortium on Chicago School Research found that learning in many poor performing high-poverty schools in the system was constrained by persistent weak curricular coherence and slow pacing (Smith, Smith and Bryk, 1998).

We have very little information about the effects of within grade curricular coherence on learning in the South African context. This article draws on data from a study (Reeves, 2005) which investigated relationships between variations in measures of opportunity to learn and gains over the academic year[1] in 1001 grade 6 students' mathematics learning in classrooms in schools serving low income communities in the Cape Peninsula in South Africa's Western Cape Province. In the study's regression modelling and hierarchical linear modelling of opportunity to learn data and learning gains, measures of within grade curricular coherence *per se* did not emerge as a direct predictor variable for gains.

Nevertheless, statistical data exploration suggested that clear logical within grade content sequencing is associated with greater grade level content

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1 Mathematics pre- and post-tests were administered at the beginning and end of the third term of the academic school year. Achievement gain was measured as the difference between the pre- and post- tests.

coverage and contributes towards increases in curricular pacing across grades.[2] By implication, the Cape Peninsula findings suggest that variations in the internal coherence of the sequencing of curriculum content over the school year could partly explain why content coverage and curricular pacing differs across classrooms. In line with Schmidt's (2005) and Carroll's (1963) assertions, the findings indicate that, if curriculum content is not presented to learners in ways that are logically and conceptually sequenced and linked, they may need more time to learn.

Guidance in South Africa's curriculum documents with attaining within grade coherence

Unlike previous apartheid syllabus-based curriculum documents, documents for South Africa's first post-apartheid school curriculum, *Curriculum 2005* (C2005) (introduced in 1997) did not stipulate the concepts and content teachers were expected to cover in each grade (DoE, 1997 a, b and c). Instead documents provided fairly 'open-ended' more skills-based outcomes for each of the three phases of the nine years of General Education (grades 1–9) – Foundation Phase (grades 1–3), Intermediate Phase (grades 4–6) and Senior Phase (grades 7–9) (DoE, 1997a, b and c). Essentially schools and teachers had control over the selection, sequencing or ordering, and pacing of concepts and content covered within and across grade/s.

Implicit in the lack of grade level specification in the intended curriculum was the assumption that teachers, as competent and autonomous professionals, could and would ensure that all learners achieved the outcomes for each phase of each learning area (Muller, 2006). Underlying this assumption was the notion that teachers had strong enough internalised conceptual schema to ensure that the necessary specialised core knowledge was made available to learners over each school phase in a way that the structured or conceptual relations within (and across) the subjects or disciplines were made apparent. By the late 1990s empirical research began to show that this was a vain assumption in the South African context.

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2 Analysis of opportunity to learn data on content coverage and curricular pacing in the study showed evidence of very low within grade topic coverage and very slow curricular pacing across grades 5 and 6. For example, the average coverage of grade 6 level topics and subtopics in the sample of grade 6 classes was 22%.

Concerns about the implementation of *Curriculum 2005* began to surface largely as a result of research which suggested that the lack of 'a conceptual roadmap' (Taylor, Muller and Vinjevold, 2003, p.133) in curriculum documents primarily disadvantaged children in schools serving historically disadvantaged communities (Taylor and Vinjevold, 1999). Evidence suggested core knowledge that learners needed to succeed at higher levels of education was not being made available to many learners. Research suggested that it was poorly trained teachers in schools in low income contexts who were most in need of guidance regarding the subject knowledge that should be covered within and across the years of schooling (Muller, 2006).

Subsequent to a *2000 Review Report* (Review Committee, 2000), *Curriculum 2005* was revised through *National Curriculum Statements* (RNCS) specific to each subject area (Department of Education/DoE, 2002). What these revisions marked was a shift from a model where teachers were expected to make their own decisions around the selection, sequencing and pacing of content, towards a relatively more highly specified and structured knowledge-based curriculum which expressed the skills, concepts and content learners were expected to learn at each grade level. At the level of official documents, the curriculum for mathematics was revised through 'mediating features' (Fullan, 1982) such as increased clarity in grade level content and more explicit across grade progression. In contrast to Curriculum 2005, external control over the rules regulating the selection, sequencing and pacing of mathematics knowledge was strengthened through the *Revised National Curriculum Statement's* assessment standards.

In mathematics, the assessment standards (DoE, 2002) were organised around five core content areas, namely: *Number, operations and relationships*; *Patterns, functions and algebra*; *Space and shape (geometry)*; *Measurement*; and *Data handling*. Within each of these content areas, the curriculum provided a number of specified 'clusters' of objectives for each grade. For example, the content area *Number, Operation and Relationships* for grade 6 learners covered '*Recognising, classifying and representing numbers'*; '*Application of numbers to problems*'; '*Calculation types involving numbers'*; '*Recognising and using properties of numbers*'. For each of these objectives, the curriculum specified topics to be covered. For example, for the objective '*Recognising, classifying and representing numbers',* learners were expected to cover:

- counting forwards and backwards in decimals;
- representing and comparing whole numbers to 9-digit numbers;
- common fractions with different denominators including tenths and hundreds;
- common fractions including percentages;
- decimal fractions to at least two decimal places;
- 1 in terms of its multiplicative property;
- multiples of any 2-digit and 3-digit whole number;
- prime numbers to 100; place value of digits in whole numbers to 9-digit numbers;
- equivalent forms of the rational numbers including common fractions with 1-digit or 2-digit denominators, decimal fractions to 2 decimal places, and percentages.

Mathematics teachers were given much clearer signalling of expected within grade content coverage and across grade curricular sequencing and pacing. The assessment standards provided an indication to teachers of the 'total' mathematics content to be sequenced over each school year. However, the revised curriculum documents did not show the order in which curriculum topics and sub-topics were intended to be sequenced and organised within each grade. Teachers were expected to exercise their own judgment when deciding on the order in which to cover mathematics content over a single academic school year.

Support was offered in the *Teacher's Guide for the Development of Learning Programmes* for mathematics (DoE, 2003) with regard to making decision about within grade sequencing of curriculum content. The guidelines suggested that attention to the various content areas should be spread across the year. They suggested that time should not be allocated to each of the five content areas "on a once a year basis but rather a number of time allocations per year, as the knowledge and skills developed" in one content area "complement the knowledge and skills to be developed in another" (DoE, 2003, p.21). The *Guide* emphasised the conceptual interdependence of various topics and content areas, for example, by stating "it is, for example, impossible to study measurement without having an understanding of numbers and operations involving numbers" (DoE, 2003, p.20). It emphasised that mathematics

> is developmental, hierarchical and dependent – learners must first be familiar with and be able to use positive whole numbers before they can deal with fractions or negative numbers and these must in turn be internalised before the learner begins to use irrational numbers. Similarly one cannot study compound events involving probability without having an understanding of simple events (DoE, 2003, p.20).

Guidelines also stated that sequencing of topics from the different content areas is “reasonably arbitrary”, and that there is no single best organisation of a year’s schedule of work (DoE, 2003, p.33).

The South African school curriculum revision process, aimed at bridging gaps between policy and practice, has been ongoing, as is reflected in a 2009 national curriculum review (see DoE, 2009), and the more recent drafting of *Curriculum and Assessment Policy Statements* (CAPS) for each school subject (see DoBE, 2011). The *Curriculum and Assessment Policy Statements* for mathematics (DoBE, 2011) now provide teachers with sequenced mathematics content topics to be taught in each term. The documents reiterate that ‘the order of content is not rigid’ (for example, teachers may need to address any ‘gaps’ in learner knowledge and skills whilst trying to cover the grade level mathematics). . . “but care must be taken not to teach content areas that involve measurement before the basic operations such as addition, subtraction, multiplication and division have been mastered at the required level” (DoBE, 2011, p.18).

Earlier we alluded to the fact that concern has been expressed about the increased levels of specificity and guidelines in the *Curriculum and Assessment Policy Statements*. A critique is that these increases may bring about a form ‘bureaucratic accountability’ (Darling-Hammond, 2001 in Wits Education Policy Unit, 2005) which undermines teachers’ autonomy to exercise their professional judgement in making pedagogical and curricular decisions. We believe that, even though the new CAPS documents for mathematics (DoBE, 2011) provide teachers with sequenced mathematics content topics to be taught in each term, attention will still need to be paid to the extent to which curriculum content is coherently presented to learners within particular school grades.

Teachers may not implement the CAPS as intended. As Posner and Strike (1976, p.671) note, other factors such as “teachers’ interests or competencies”, “time schedules”, and “materials and facilities available” are “powerful determinants” in the implementation of planned programmes. Teachers’ curricular and pedagogical decisions are influenced by their subject matter knowledge (SMK), pedagogical content knowledge (PCK), curricular knowledge as well as their beliefs about mathematics and years of teaching experience (Shulman, 1986; Ball, Thames and Phelps, 2008). Teachers may need to alter the sequencing, for example, when they find they have to adjust or adapt plans in relation to the knowledge that learners have versus the knowledge that the CAPS anticipate learners to have.

In the next section we offer a methodology for assessing within grade curricular coherence in teachers' implementation of the mathematics curriculum in different classrooms. The methodology was developed for the Cape Peninsula study referred to earlier (Reeves, 2005). This study collected detailed opportunity to learn data from 38 grade 6 and 24 grade 5 classes in a randomly selected sample of 24 schools serving low income communities in the Cape Peninsula in the Western Cape Province.

The data collected included information on the order in which mathematics topics were covered across the school year in each grade 6 class in 2003. This data make it possible to analyse what teachers in the sample of schools did with the discretion available to them when they were expected to exercise their own judgment in deciding on the order in which to cover mathematics content. The analysis provides insight into the extent to which in-service teachers are able to plan and enact a year's curriculum as a coherent entity.

We start with methods for collecting data on sequencing in the enacted curriculum, and then discuss the analytical processes and instruments used to analyse variations in the degree to which mathematics curriculum content is coherently presented to learners over the school year.

Methods for collecting data on within grade content sequencing

Rather than relying on an examination of teachers' intended year plans or schemes of work, the Cape Peninsula study relied primarily on information garnered from an examination of written work in learners' notebooks. Learners in South Africa are usually asked to write work in their notebooks in every mathematics lesson. However, in case learners had not actually completed work in their notebooks in every lesson, at the beginning of the school year two learners in each selected grade 6 classes were asked to keep diaries on the daily content of their classroom instruction.

The main data collection methods used to re-construct the order in which learners covered mathematics contents in each class was to map the content sequence directly from the two most comprehensive or 'best' notebooks in each class. Learners' reports in the diaries were used as supplementary data sources. This data collection took place in the last two weeks of each of the first three terms (of four terms/quarters) of the school year. Obtaining information each term was considered to be more feasible and reliable or accurate than 'once off' towards the end of the school year. As far as was possible, in mapping of the content sequence, data collectors tried to record in-depth information on the topics covered rather than only outlining the broad topics covered. For example, by recording '*multiplication of 2-digit by 2-digit whole numbers'*, instead of simply recording '*multiplication*'.

Analytical processes and instruments for measuring variation in curricular coherence in mathematics over the school year

Because disciplinary expertise is required to exercise judgment over levels of curricular coherence, a highly qualified and experienced mathematics teacher, who had served on the committee that developed the revised *National Curriculum Statement* for mathematics, was asked to examine the data mapping the content sequence for each school class. The expert was asked to exercise her professional judgement in determining whether learners studied mathematics topics and sub-topics in an appropriately coherent sequence.

The mathematics expert used the 3-point scale to rate levels of curricular coherence on the two-dimensional matrix shown on Table 1 below. She was asked to make an estimation of levels of curricular coherence, firstly by assessing '*topic sequence*', and then '*content area spread*' across the three school terms. A quantitative rating for curricular coherence in each grade 6 class was obtained by combining the expert's rating for 'topic sequence' and 'content area spread'.

'*Topic sequence'* is a measure of the extent to which the organisational sequence in each class:

(a) reflects the hierarchical and logical progression of mathematics concepts and procedures. For example, the extent to which content area topics or concepts covered earlier are "logical prerequisites" for others that follow, in other words, it is "logically necessary to understand" the earlier concept or topic in order to understand the more complex concepts or topics that come later (Posner and Strike, 1976, p.675); and

(b) conceptually develops and creates connectivity within the subject. For example, the extent to which the sequence is "structured in manner consistent with the way" in which content area topics or concepts are related or connected to one another (Posner and Strike, 1976, p.673).

The idea behind rating '*content area spread'* in assessing the level of curricular coherence is to include a measure of the extent to which teachers' sequencing of the year's work incorporates all the content areas.[3] To represent a composite mathematics curriculum, a year's schedule of work needs to cover all five content areas in the curriculum (Number, Patterns, Geometry, Measurement and Data handling). If only one or some of the five content areas are presented, (for example, if the majority of topics are related to one or two of the content areas and other content areas are omitted), the schedule of work does not represent a composite mathematics curriculum.

A key challenge for mathematics teachers is that, because they need to structure their schedule of work so that "the knowledge and skills developed" in one content area "complement the knowledge and skills to be developed in another" content area, each content area needs to be presented not just "on a once a year basis" but a number of times across the year (DoE, 2003, p.21). In other words, yearly programmes of work need to reflect connectivity and co-ordination not only between topics within a single content area, but also between topics in different content areas.

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3 It is important to point out that the mathematics expert was not assessing 'content coverage' (variations in the overall number of mathematics topics and sub-topics covered during the year) or 'content emphasis' (variations in the amount of time or number of lesson periods devoted to various topics). She was not assessing grade level alignment of the topics with curriculum documents here. For a discussion of the methodological procedures used for collecting and analysing data on other dimensions of opportunity to learn see Reeves and Muller, 2005.

Table 1: Topic sequence and content area spread matrix used to rate levels of curricular coherence

	1	2	3
Topic sequence	Topic sequence mostly does not reflect any sequential development of maths concepts or procedures or it is difficult to discern conceptual development. Does not reflect links between sequential topics.	Topic sequence reflects sequential development of some maths concepts or procedures; however, links between sequential topics are not always clear. (For example, whole-number work and fraction-work is mixed up, or lots of operations with whole numbers are presented before place value and counting, or operations with whole numbers do not always progress from smaller numbers to bigger numbers).	Topic sequence reflects gradual and sequential development of most maths concepts or procedures with isolated exceptions. (For example, whole-number-work progresses from number concept development such as place value and counting, factors and multiples to operations with numbers from smaller numbers to bigger numbers. Or, fraction and decimal work progresses from recognition and representation to equivalence, then operations). Content reflects links between sequential topics (for example, fractions and decimals).
Content area spread	Content coverage shows very little spread of the five content areas across the three (of four) school terms. (For example, only up to three or four of the five content areas (each with an array of topics and sub-topics) dealt with three-quarters of the way through the school year; only one or two content areas are dealt with more than once.	Content coverage shows some spread of content areas across the three (of four) school terms. (For example, in most terms only one or two content areas are covered; up to four content areas dealt with three-quarters of the way through the year; only three content areas are dealt with more than once.	Content coverage shows adequate spread of content areas across the three (of four) school terms. For example, first term, more than one content area; 2nd and 3rd terms more than two content areas; all five content areas dealt with so far; at least four content areas are dealt with more than once.

In distinguishing between the different levels, the mathematics expert was asked to bear in mind that the study was examining 'naturally occurring' variations in the variable of interest. A major constraint with investigating naturally occurring differences, as opposed to investigations that involve focused intervention, is that not even the best classes are likely to be exposed to optimal levels of the variables of interest (Rowan *et al.*, 2002). To demonstrate how variation in curricular coherence, was assessed, the expert's coding of the data from three examples, representative of the data collected, are provided. The mathematics expert used her knowledge of disciplinary principles to assess curricular coherence.

To make the evaluative criteria more explicit, an analysis is provided in the second column of each of the three illustrative examples. The analysis is based on the disciplinary principles which guide topic sequencing and content area spread: logical progression, conceptual development and connectivity as well as coverage of content areas over the year and the frequency of occurrence.

The mathematics expert assessed *Example 1* (Table 2 below) as showing poor topic sequencing (rating 1) and poor content area spread (rating 1). In the first three terms the teacher only dealt with one content area (*Number, operations and relationships*). The expert could discern 'little conceptual development' in the sequencing of content 'for *whole number'* and identified 'gaps in sequence for *fractions*'.

Table 2: Example 1

Example 1	Analysis
First term <u>Number</u> Addition and subtraction of up to 4-digit numbers Place value of up to 4 digit numbers Long division **Second term** <u>Number</u> Proper fractions Addition and subtraction of fractions with same denominators Addition and subtraction of fractions with different denominators **Third term** <u>Number</u> Common fractions with denominators that are multiples of each other and with 1- or 2- digit denominators Addition of fractions with the same denominator Addition of fractions with different denominators Subtraction of fractions with the same denominator Subtraction of fractions with different denominators Conversion of mixed numbers to improper fractions Identifying fractions as proper, improper, mixed numbers Addition of fractions with different denominators Subtraction of fractions with different denominators Multiplication of fractions	Topic sequencing is weak as there is no evidence of consistent, logical progression or conceptual development throughout the three terms. For example, in the first term, the content is organised without due consideration of the progressive and hierarchical structure of mathematics. Place value, which is the key to the understanding of whole number, lays the foundation for addition and subtraction of numbers and should conceptually precede number operations. Learners need to experience multiplication and division as inverse operations to help transform more complicated problems and to experience the inter-connectivity between operations. There is no evidence of this, and the inclusion of division in the first term without linkage to multiplication creates isolated and fragmented understanding of mathematics. Fractions appear to be a mix of identifying and converting between different types of fractions and operations with fractions. Learners need to be able to add and subtract fractions with same dominators before they can move to operating with fractions with different denominators. The development of a logical mathematical conceptual plan is lacking in this example of data mapping of content. Only one of five content areas, *Number, operations and relationships* is dealt with throughout the first three terms of the year. There is no evidence of *Patterns, functions and algebra*; *Space and shape*; *Measurement* and *Data handling* content areas which indicate poor spread. Some mathematical content is revisited during terms two and three, but it is limited exclusively to fractions.

The expert assessed the sequencing of topics in *Example 2* (Table 3 below) as not reflecting conceptual development – no obvious links between consecutive topics was evident (rating 1). *Example 2* was deemed to reflect relatively good content area spread (rating 3). Although very little of each content area was dealt with each time, *Number, operations and relationships*, *Patterns, functions and algebra*, *Space and shape* and *Measurement* were repeated, and *Data handling* was presented once.

Table 3: Example 2

Example 2	Analysis
First term Shape and space Rectangular prisms, faces Number 8 x tables and 9 x tables and 12 x tables Addition – 2-digit numbers Addition up to 3-digit numbers and subtraction Addition – single digit Patterns, functions, algebra Number patterns – 3- and 4-digit numbers Number Multiplication up to 2-digit numbers Measurement Conversions – km to m and ml to l and kg to g Number Recognising mathematics in newspapers Recognising mathematics in shopping and on waste products **Second term** Data handling Bar graphs Line graphs Space and shape Describing, sorting and comparing geometrical properties of 3 D objects according to i) shapes ii) number of sides iii) length of sides Number Addition of rand and cents **Third term** Patterns, functions and algebra Fibonacci numbers – Fibonacci sequence - investigating numeric and geometric patterns Measurement Length using mm, cm, km Shape, space (geometry) Right angles and angles smaller than and greater than right angles	Topics sequencing is weak as the data mapping of content does not reflect logical, conceptual mathematical development. For example, the content area *Numbers* starts with 2-digit addition and leads to 3-digit addition but then returns to single digit addition. There is weak evidence of the hierarchical structure of mathematics which involves moving progressively over time towards a deeper understanding of concepts. Many topics are superficially covered and lack conceptual depth. For example, in the first term, *Shape and space* includes the faces of rectangular prisms while *Patterns, functions and algebra* is solely comprised of number patterns with 3- and 4- digit numbers. There is very little connectivity between topics and the data mapping of content appears to be a random list of unrelated mathematics topics. Addition and subtraction of numbers as inverse operations is ignored and many topics are simply excluded, such as subtraction and division of whole numbers, common fractions, decimals and 2D shape and space. The spread of content areas appears to be relatively good: four content areas in the first term, three in the second term and three in the third. However, there is too little mathematical content and a lack of conceptual development within the topics. Number patterns are mentioned in the first term and again in the third term but there are no geometric patterns or number sentences.

The expert assessed the sequencing of the topics covered in *Example 3* (Table 4 below) as 'relatively logical' and 'mostly' reflecting conceptual development (rating 3). For example, 'fractions links to decimals', and 'decimals links to measurement'. However, *Example 3* was assessed as limited in terms of spread of content areas (rating 1). Only *Number, operations and relationships* was repeated. *Measurement* and *Data handling* were presented once. *Patterns, functions and algebra* was touched on only in terms of *counting,* whilst *Space and shape* was not dealt with at all.

Table 4: Example 3

Example 3	Analysis
First term Number Whole numbers – Counting in 2s, 3s, 5s, 10s, and 100s Addition and subtraction Comparing whole numbers - 4-digit and 6-digit numbers, odd and even numbers, place value 4-digit numbers Dates (no calculations/conversions) Adding and subtracting in columns – 4- and 5-digits Multiple operations of whole numbers Multiplication – tables up to 12 x 12 – 2-digit by 2-digit, and 3-digit by 2-digit Division – 3-digit by 1-digit, 3-digit by 2-digit, remainders. **Second term** Number Multiplication 2- by 2-digit, and 3- by 2-digit Distributive properties with whole numbers Division 3- by 1-digit, and 3- by 2-digit whole numbers Division with remainders Data handling Pictographs (many to one correspondence) - Population data Pie graphs - Re-cycling data Number Fractions – halves and quarters, third of 18 Equivalent fractions and improper fractions Mixed numbers Addition and subtraction of fractions (including mixed numbers **Third term** Number Addition of fractions with the same denominators and with denominators that are multiples of each other for example ¼ + $^{2}/_{3}$ Addition of fractions with the same denominators and with denominators that are multiples of each other and mixed numbers	The sequencing of topics in the content area *Number, operations and relationships* shows logical progression and conceptual depth especially in whole and rational number. There is good linkage between addition, subtraction, multiplication and division of whole numbers and evidence of developmental stages within the number ranges. The topic of fractions includes recognition, equivalence as well as addition and subtraction of fractions and a logical connectivity to decimal fractions. However, there is an over-emphasis on whole and rational number at the expense of the other topics and opportunities to create further developmental links have been lost. The inclusion of *Data handling* in the second term has no logical relevance, though in the third term, *Measurement* following decimals gives learners the opportunity to use their decimal knowledge in the context of measurement. There is poor spread of the five mathematical content areas: mostly *Number, operations and relationships* is presented in each of the three terms, with some *Measurement* and *Data handling* but no *Patterns, functions and algebra (except for counting),* or *Space and shape.*

Subtraction of fractions with the same denominators and with denominators that are multiples of each other Dividing whole numbers by fractions, for example $^{3}/_{5}$ of 15 Representing fractions and converting to decimal fractions Converting to decimals by division as in 2 ÷100 = $^{2}/_{100}$ = 0,02 Place value of decimals for example 0,12 is 0 ones, 1 tenths 2 hundredths etc. (up to 3 decimal places) Building up and breaking down decimal fractions using fractions with numerators that are multiples of 10 Addition of decimal fractions Measurement Capacity – litres and ml Mass – kg and g Decimal fractions in the context of capacity and mass	

Topic sequencing in only 8 per cent of the 38 grade 6 classes was judged as reflecting appropriate sequential development of mathematics concepts or procedures (although not necessarily optimal levels). In 76 per cent of the classes topic sequencing was judged as mostly not reflecting logical conceptual development. Sequencing in the remaining 16 per cent of the classes fell in-between these two categories, and reflected some but limited sequential development.

An analysis of the percentage of the grade 6 classes that the mathematics expert assessed at the different levels of spread of content areas showed that only 50 per cent of the grade 6 classes showed adequate spread of content areas across the three terms. In 24 per cent of the classes curricular spread was deemed to show no or very little spread of content areas across the three terms. 26 per cent of the classes showed some but insufficient spread of content areas across the three terms.

What the analysis also revealed is that the sample of learners' experience of within grade curricular coherence was uneven. The spread of content areas across the first three terms (of four terms) in only half of the grade 6 classes was deemed generally adequate. The order in which mathematics topics were covered across the school year for three quarters of the grade 6 classes was judged as not reflecting coherent development of mathematics concepts, skills or procedures. Although there were variations in content area spread and the order in which topics were covered differed across different grade 6 classes, mathematics in the majority of the classes studied did not reflect sequential links and developmental complexity across all five content areas. For most learners mathematics was not presented in a coherent and composite manner over the school year.

When data collection for the Cape Peninsula study took place in 2003, the *National Curriculum Statements*, although officially adopted, were not yet in use at the grade 5 and 6 levels. A more recent study by Carnoy, Chisholm, Addy, Arends, Baloyi, Irving, Raab, Reeves, Sapire and Sorto (2011b) collected similar opportunity to learn information from a sample of over sixty grade 6 low socio-economic classrooms in the North West province of South Africa in 2009. In 2009 the *National Curriculum Statements* were supposed to be implemented at the grade 6 level. Despite the increased clarity in grade level content in the official curriculum documents in use, data from the Carnoy *et al*'s study similarly show that the order in which teachers in the North-West sample covered mathematics content over the year in 2009, mostly does not reflect curricular coherence. The majority of the teachers in the North-West sample did not appear to have a clear sense of how to structure their coverage of topics over the year 'in the disciplinary sense' (Schmidt *et al.*, 2005).

Our analysis of the manner in which the sample of teachers presented curriculum content to learners within a school grade provides insight into the knowledge teachers need if they are to exercise professional judgement in putting topics and sub-topics together in a coherent sequence. In the discussion which follows, we consider some of the implications of our data analysis for mathematics teacher education and development.

Discussion

As we have noted, the new CAPS documents for mathematics (DoBE, 2011) provide teachers with sequenced mathematics content topics to be taught in each term. This form of guidance is useful particularly for teachers of mathematics who are not well-specialised in the subject. We argue that teachers also need to *understand* the importance of attaining coherence in the curriculum they make available to their learners over the school year. They need to be aware of the role logical within grade sequencing plays in facilitating content coverage and curricular pacing. If teachers do not understand this, they may not adhere to the plans, or they may adjust or adapt them inappropriately, for example, when addressing gaps in learner knowledge.

Other moves on the part of the Department of Basic Education, aimed at bridging gaps between policy and practice, include the provisioning of workbooks and the introduction of a centralised national catalogue of approved textbooks for General Education (grades 1–9). Every learner is to have his/her own textbook for each of his/her subjects. We suggest that, for teachers to use carefully sequenced workbooks and textbooks as they are intended, they need to understand how well-structured workbooks and textbooks can be used to help bring coherence into implementation of their mathematics work schedules. They need to be shown how such material systematically organises and sequences content and concepts to consolidate and build new knowledge on the firm foundations of earlier linked knowledge.

Authors such as Darling-Hammond (2001), Morrow (1989); Hoyle and John (1995) (in Wits Education Policy Unit, 2005, p.11) contend that knowledge should form the basis for professional action. The data presented in this article suggests that many teachers do not have the necessary knowledge to exercise professional judgement in putting topics and sub-topics together in a coherent sequence. We argue that, for teachers to become more autonomous and plan, enact, and responsively adapt a year's curriculum as a coherent entity underpinned by internal disciplinary principles, they first need to recognise that mathematics is not simply a collection of isolated and unrelated topics and sub-topics.

If, "a coherent curriculum is one whose parts are unified and connected by a sense of the whole" (Beane, 1995: abstract), then teachers also need to have a sense of the curriculum as a whole to ensure coherence in their programme of work over a school year. They need to develop an understanding of the principles underpinning the inherent structure of the discipline "from which the subject-matter derives" (in this case, mathematics) (Schmidt *et al.*, 2005, p.529). They need to have a strong enough hold over the school subject to be able to comprehend "inter-linkages amongst the various topics" and sub-topics (Sharma and Ahluwalia, 2010, p.94).

For Redish (2003 in Sharma and Ahluwalia, 2010, p.94) and others in the field of physics "the key issue in bringing coherence through organisation of knowledge in more systematic and logically connected ways, is construction of a cognitive network", or a relational mental map of the subject field.

Sharma and Ahluwalia (2010, p.96) suggest a strategy for getting teachers to create “a visual survey of conceptually connected material” where they “explore all the possible alternative paths to reach and link one part of the subject to the other”. They present what they term “an architectural view point” and introduce the notion of “an image-ability map” which, they say allows students “to gain an overview of a domain of knowledge” and an understanding of “the intra-connectivity” of topics and concepts (Sharma and Ahluwalia, 2010, p.95). Such an approach not only serves as a cognitive resource which teachers could draw on later, but also acts as a “pictorial reminder” that mathematics (or in their case physics) as a subject “has a well-knit hierarchical structure” (Sharma and Ahluwalia, 2010, p.96).

We suggest that there is also the potential for the CAPS documents to be used as “an instrument to empower teachers’ rather than ‘as an instrument to control teacher’s work” (Wits Education Policy Unit, 2005, p.7). Mathematics experts could use the sequenced mathematics content topics to be taught in each term, along with other exemplars of ‘ideal’ sequencing of mathematics content within each school year, as resources for helping teachers to understand the principles that generate the exemplars, and for making the logic underpinning the coherent presentation of within grade level topics and sub-topics in mathematics explicit.

Conclusion

In this article we refer to the disciplinary principles which guide curricular coherence within the grade 6 mathematics curriculum over a single academic year. We argue that these principles involve issues of content area spread and topic sequencing. We have selected three principles as the essential underpinnings of the concept of curricular coherence within this context (Schmidt *et al.*, 2005, p.527–530): Sequencing of curricular content that reflects

1. Conceptual progression and the logical and hierarchical structure of mathematics [for example, content area topics or concepts covered earlier are “logical prerequisites” for others that follow (Posner and Strike, 1976, p.675)]

2. Connectivity and co-ordination between topics and concepts in the different content areas within the subject [for example, sequencing that is

"structured in a manner consistent with the way" in which topics or concepts are related or connected to one another (Posner and Strike, 1976, p.673)]

3. A composite mathematics curriculum covering all five content areas of the curriculum (*Number, operations and relationships*; *Patterns, functions and algebra*; *Space and shape (geometry)*; *Measurement*; and *Data handling*).

We contend that, in order to organise and present all grade level content area topics in a coherent sequence over the school year, mathematics teachers need to develop an understanding of the hierarchical structure of school mathematics, and of moving progressively over time towards the understanding of the deeper structure of mathematics. They need to have a sense of the mathematics curriculum as a whole, and a strong enough knowledge of the subject to be able to comprehend connections between the different topics in the different content areas studied within the subject.

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