COMPLEXITY OF PRACTICAL WORK IN SCIENCE CURRICULA AND NATIONAL EXAMS: ANALYSIS OF RECONTEXTUALISING PROCESSES

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The study is focused on the level of complexity of practical work in science curricula and national external assessment with regard to the secondary school discipline of Biology and Geology in Portugal. This level of complexity is appreciated through the conceptual demand of practical work as given by the complexity of scientific knowledge and cognitive skills and the relation between theory and practice. The recontextualising processes that may have occurred in the exams were analysed by studying the relation between curriculum and exams. The study makes use of theories and concepts of the areas of psychology and sociology, particularly Bernstein's theory of pedagogic discourse. The results show that the level of conceptual demand of practical work varies according to the specific curricular text under analysis, i.e. Biology or Geology. Practical work as assessed in the exams recontextualises the curriculum in the direction of lowering its level of conceptual demand. In methodological terms, the article explores assumptions used in the analysis and presents innovative instruments.

Keywords: practical work; science process skills; conceptual demand

INTRODUCTION

The role of practical work in offering students the opportunity to experience the process of scientific investigation is one of the arguments for practical work in science education (Hofstein & Kind, 2012; Lunetta et al., 2007; Osborne, 2015). Students are expected to both learn scientific knowledge and mobilize science process skills whenever they are doing investigative practical activities. The nature and complexity of practical work in science curricula and national exams and the recontextualising processes that may have occurred between them should be analysed and discussed because these are aspects that broadly guide textbook authors and teachers' practices.

In science education, as well in other areas of knowledge, it is essential that there are no discontinuities between curriculum, pedagogical practice and assessment (e.g. Britton & Schneider, 2007; Duschl, Schweingruber & Shouse, 2007). For that reason these different texts and contexts "should be conceived of, designed, and implemented as a coordinated system" (Duschl et al., 2007, p. 347). In the specific case of external assessment, evidence from several studies indicates that national exams limit the teaching and learning process and also the classroom assessment tools (Hamilton, 2003). If exams and curriculum are inconsistent, teachers tend to focus on what is assessed in the exams rather than on what is presented in the curriculum and in this way the content that is not tested tends to be ignored in pedagogical practice (Britton & Schneider, 2007). The external assessment can push "teaching and learning in undesirable directions that are counterproductive to the goals of scientific literacy" (p. 1009). However specific types of assessment have the potential to promote particular forms of effective teaching.

The study is focused on the analysis of both the Portuguese curriculum and the national exams for secondary school biannual discipline of Biology and Geology (ages 16^{-}-17^{+}). In Portugal likewise many Latin countries, Biology and Geology, although epistemologically distinct, have traditionally been part of the same discipline (often but not always called Natural Sciences). Theoretically, the study is multidisciplinary, making use of theories and concepts of the areas of psychology and sociology, particularly Bernstein's theory of pedagogic discourse (1990, 2000).

Bernstein develops a theory about the production and reproduction of pedagogic discourse, in which he considers the complex set of relations between various fields and contexts of what he calls pedagogic device. Throughout this process, recontextualisations at the various levels of the pedagogic device can take place and for that reason the pedagogic discourse is not the mechanical result of the dominant principles of society, which constitute the general regulative discourse (GRD). As a result of the official recontextualisation of the GRD, namely at the level of the Ministry of Education and its agencies, the official pedagogic discourse (OPD) is produced. This discourse is expressed, for example, in curricula and in national exams.

Bernstein's model also evidences that the official recontextualisation field is influenced by the fields of economy and symbolic control and defines *the what* and *the how* of the pedagogic discourse. *The what* refers to the knowledge and skills that are the object of the teaching and learning process and *the how* is related to the way in which the teaching and learning process occurs.

In particular the relation between curricula and national exams was analysed in this study to explore recontextualisation processes that may have occurred between the message conveyed in these official documents, with regard to different dimensions of *the what* and *the how* of pedagogic discourse related to practical work. The study addresses the following research problem: What are the messages transmitted by the official pedagogic discourse (OPD) expressed in both the curriculum and the national exams of Biology and Geology of secondary school, with regard to their level of complexity of practical work, and what is the extent to which recontextualising processes do occur?

Varying with authors, practical work can have different meanings. Hodson (1993) considers practical work as a broad concept which includes any activity that requires students to be active. Millar, Maréchal e Tiberghien (1999) limit the definition presented by Hodson (1993) to consider that practical work is 'all those kinds of learning activities in science which involve students at some point handling or observing real objects or materials (or direct representations of these, in a simulation or video-recording)' (p. 36). In the same line, Lunetta, Hofstein and Clough (2007) give the following definition of practical work: 'learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world' (p. 394).

The meaning of practical work in the present study is made more precise in that considers that it must mobilize science processes skills. These skills were considered as ways of thinking more directly involved in scientific research, such as observing, formulating problems and hypotheses, controlling variables and predicting (Duschl, Schweingruber and Shouse, 2007). Thus, practical work is defined as: all teaching and learning activities in the sciences in which the student is actively involved and that allow the mobilization of science processes skills and scientific knowledge and that may be materialized by paper and pencil activities or observing and/or manipulating materials.

The level of complexity of practical work can be appreciated by its level of conceptual demand. In the context of the research that has been carried out by the ESSA Group (Sociological Studies in the Classroom, Institute of Education, University of Lisbon) within Bernstein's theory, the concept of conceptual demand is defined as the level of complexity of science education as given by the complexity of scientific knowledge and the strength of intradisciplinary relations between distinct knowledge and also by the complexity of cognitive skills (Morais & Neves, 2016).

METHOD

The analysis of the Biology and Geology secondary school curriculum was focused on two official documents which contain directions for the teacher: 10th Biology and Geology syllabus and 11th Biology and Geology syllabus (in force since 2002 and 2003, respectively). Although part of the same discipline and of the same curriculum, Biology and Geology come in the curriculum as two distinct subjects, with strong boundaries between them. The analysis of the national exams involved 26 exams, from 2006 to 2011.

The whole curriculum was segmented into units of analysis but the units of analysis with a specific reference to practical work (requiring the mobilization of science process skills) were the only ones considered in this study. For the same reason, the analysis of national exams considered only the questions which focused on practical work, i.e., questions that mobilised science process skills. Each question was taken as a unit of analysis.

The level of conceptual demand was determined through the analysis of specific dimensions of *the what* and of *the how* of the OPD (Figure 1). The first corresponds to the level of complexity of scientific knowledge and cognitive skills and the second to the strength of intradisciplinary relations between theory and practice. The discontinuities between the curriculum and the national exams were studied through the recontextualising processes that may have occurred between the messages of these official documents.

Three instruments were constructed in order to characterise the message underlying each one of the units of analysis, and consequently the OPD transmitted by both the science curriculum and the national exams, with regard to the conceptual demand of practical work. The construction of the instruments followed a mixed methodology (Creswell & Clark, 2011; Morais & Neves, 2010; Teddlie & Tashakkori, 2009), using qualitative and quantitative approaches. The text that follows contains a brief description of the instruments constructed and how they were used, and gives also some examples to show how analyses were made.

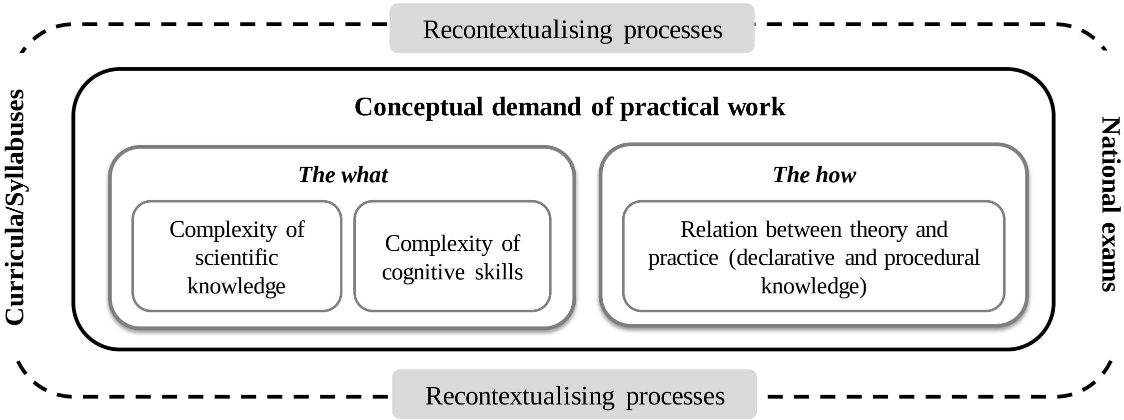

Figure 1. Diagram of dimensions, related to *the what* and *the how* of practical work, analysed in the secondary school Biology and Geology curriculum and national exams.

The instrument for analysing the complexity of scientific knowledge was based on the distinction between facts, generalized facts, simple concepts, complex concepts and unifying themes/theories, following several authors (e.g. Brandwein et al., 1980; Cantu & Herron, 1978; Duschl et al., 2007; Pella & Voelker, 1968). For instance, simple concepts have a low level of abstraction, defining attributes and examples that are observable (Cantu & Herron, 1978). Complex concepts correspond to abstract concepts proposed by Cantu and Herron (1978) and "are those that do not have perceptible instances or have relevant or defining attributes that are not perceptible" (p.135). Table 1 presents an excerpt of this instrument and examples of units of analysis which illustrate different degrees of complexity.

Table 1. Excerpt of the instrument to characterise the complexity of scientific knowledge.

Degree 1	Degree 2	Degree 3	Degree 4
Scientific knowledge of low level of complexity, as facts, is referred.	Scientific knowledge of level of complexity greater than degree 1, as simple concepts, is referred.	Scientific knowledge of level of complexity greater than degree 2, as complex concepts, is referred.	Scientific knowledge of very high level of complexity, as unifying themes and theories, is referred.

Units of analysis:

Degree 1: [1] Search for information on the internet, in newspapers and magazines about the consequences of such situations [anthropic occupation of floodplains and coastal zones, and construction in slope zones] for populations. (*11th Geology syllabus*).

Degree 2: [2] [...] 6. When exposed to the sun, the surface of the coat of *C. dromedarius* can reach temperatures above 70 °C, while at the skin level the body temperature does not exceed 40 °C. Explain, from the data provided, how the research carried out allowed to relate the adaptation to high temperatures to the levels of transpiration presented by *C. dromedarius*. [...] (*National Exam of 2009, 1st phase*)

Degree 3: [3] [...] 6. Genetic studies in *Coccomyxa* suggest that as soon as the endosymbiotic relation with *Ginkgo biloba* was established the algae was transmitted from generation to generation. Explain how the results of those studies may relate the transmission of the endosymbiotic relation from generation to generation to the way how such relation was initiated. [...] (*National Exam of 2009, 2nd phase*).

Degree 4: [4] Collect, organize and interpret data of a different nature related to evolutionism and to arguments that support it by opposition to fixism. (*11th Biology syllabus*).

Adapted from Ferreira & Morais (2013, 2014)

Excerpt [1] emphasises facts related to the consequences for populations of the anthropic occupation of floodplains and coastal zones and construction in slope zones, and for that reason it was classified with the degree 1. In excerpt [2], the national exam question and respective recommended correction involve simple concepts related to thermoregulation. In the question presented in excerpt [3] and in the given respective correction are involved complex concepts related to the genetic transmission of an endosymbiotic relation between a plant and a green algae. If the question appealed to a relation to the model of endosymbiosis, the degree of complexity would increase to degree 4. The excerpt [4] focuses knowledge of a very high degree of complexity related to the theory of evolution.

A second instrument, for analysing the complexity of cognitive skills, was based on the taxonomy created by Marzano and Kendall (2007, 2008) with four levels for the cognitive system: retrieval, comprehension, analysis and knowledge utilization. Retrieval, the first level of the cognitive system, involves the activation and transfer of knowledge from permanent memory to working memory. "The process of comprehension within the cognitive system is responsible for translating knowledge into a form appropriate for storage in permanent memory" (2007, p.40). The third level, analysis, involves the production of new information that the individual can elaborate on the basis of the knowledge s/he has comprehended. The fourth and more complex level of the cognitive system implies the knowledge utilization in concrete situations. Table 2 presents an excerpt of this instrument.

Table 2. Excerpt of the instrument to characterise the complexity of cognitive skills.

Degree 1	Degree 2	Degree 3	Degree 4
Cognitive skills of low level of complexity, involving cognitive processes of retrieval, are mentioned.	Cognitive skills of level of complexity greater than degree 1, involving cognitive processes of comprehension, are mentioned.	Cognitive skills of level of complexity greater than degree 2, involving cognitive processes of analysis, are mentioned.	Cognitive skills of very high level of complexity, involving cognitive processes of knowledge utilization, are mentioned.

Units of analysis:

Degree 1: *No units of analysis were found.*

Degree 2: [5] [...] 3.2. Select the alternative that completes the following statement correctly. For the results of Büchner's experiment prove that the occurrence of fermentation is in some way related to the intervention of living beings (or their derivatives), it would be necessary to introduce in the procedure a device containing ...
(A) ... yeast in a sugar solution.
(B) ... yeast extract in a sugar solution.
(C) ... only a sugar solution.
(D) ... exclusively yeasts. (*National Exam of 2007, 2nd phase*)

Degree 3: [6] Classify rocks based on genetic and textural criteria. (*11th Geology syllabus*)

Degree 4: [7] [...] 6. Some authors consider Giardia as a missing link in the evolution between prokaryotic cells and eukaryotic cells, while others authors argue that it has evolved from more complex eukaryotic cells by the loss of certain organelles.
Present a possible path of investigation that would allow one of the hypotheses mentioned to be proved and the other to be rejected. [...] (*National Exam of 2006, 1st phase*)

Adapted from Ferreira & Morais (2013, 2014)

In excerpt [5] the national exam question implies the mobilization of science process skills related to the identification of the control group characteristics, which is associated with the process of comprehension. The syllabus aim presented in excerpt [6] involves the mental process of classification, associated with the cognitive process of analysis. The excerpt [7] focuses the planning of investigative laboratory activities, which is related to the cognitive process of knowledge utilization.

The analysis of the relation between theory and practice was characterized through Bernstein's concept of classification (1990, 2000), to indicate the strength of boundaries between various types of knowledge. This instrument contained a four degree scale of classification (C^{--}, C^{-}, C^{+}, C^{++}). The weakest classification (C^{--}) corresponds to an integration of theory and practice where both have equal status and the strongest classification (C^{++}) corresponds to an insulation between theory and practice. The empirical descriptors for each degree translate the relation between declarative knowledge (theory) and procedural knowledge (practice) (Roberts, Gott & Glaesser, 2010). Table 3 presents an excerpt of this instrument, followed by examples of units of analysis which illustrate different levels of classification.

Table 3. Excerpt of the instrument to characterise the relation between theory (declarative knowledge) and practice (procedural knowledge).

C^{++}	C^{+}	C^{-}	C^{--}
The focus is either on declarative knowledge only or on procedural knowledge only.	Declarative knowledge and procedural knowledge are focused, but not the relation between them.	The relation between declarative and procedural knowledge is focused, giving higher status to declarative knowledge.	The relation between declarative and procedural knowledge is focused, giving equal status to both types of knowledge.

Units of analysis:

C^{++}: [8] [...] 3. Select the alternative that fills the spaces in the following sentence, in order to get a correct statement. The study II allows to conclude, through the quantification of the seeds produced, that the ______ space selected plants with ______ dispersion capacity.
(A) urban (...) greater
(B) country (...) greater
(C) urban (...) minor
(D) country (...) minor (*National Exam of 2008, 1st phase*)

C^{+}: *No units of analysis were found.*

C^{-}: [9] The cell: The laboratory observation of uni and multicellular living beings, collected in the field, will enable the understanding of the cell as a structural and functional unit of living beings and facilitate the approach to its basic constituents. (*10th Biology syllabus*)

C^{--}: [10] Create models and simulate laboratory situations of landslide, trying to identify the factors that contribute to their occurrence. The teacher should draw attention to the analogies between the model and the geological process, stressing, however, the variables involved and the different scales of time and space in which phenomena occur. (*10th Geology syllabus*)

Adapted from Ferreira & Morais (2013, 2014)

The national exam question presented in excerpt [8] focuses on procedural knowledge only, associated with the knowledge of the scientific process of interpretation of simple experimental data, explored in the introductory text of this question. The excerpts [9] and [10] involve a relation between declarative and procedural knowledge, but in the former the higher status is given to declarative knowledge about the cell, and in the latter both types of knowledge have equal status.

In order to clarify how the same unit of analysis was classified in the study in terms of the dimensions related to *the what* and *the how* of pedagogic discourse, an illustrative example of the analysis that was made is presented:

> [11] Setting experimental devices with simple aerobic facultative living beings (e.g. *Saccharomyces cerevisae*) in nutritive media (e.g. "bread dough", grape juice, aqueous solution of glucose…) with different degrees of aerobiosis. Identification with the students of the variables to be controlled and the indicators of the process under study (e.g. presence/ absence of ethanol). (*10th Biology syllabus*)

Excerpt [11] presents a methodological guideline of the 10th Biology syllabus. With regard to *the what* of the OPD, this unit is focused on a laboratory activity, which appeals to simple concepts, related to glucose degradation in the presence and in the absence of oxygen (degree 2), and to cognitive skills involving the cognitive process of analysis, since it implicates the control of variables (degree 3). With regard to *the how* of the OPD, this unit of analysis involves a relation between declarative and procedural scientific knowledge, where equal status is given to these two types of knowledge (C^{--}).

RESULTS

Figure 2 gives a synthesis of results of the conceptual demand of practical work of both science curriculum and national exams for the three dimensions studied. These results refer to the Biology and Geology curriculum specific guidelines only and to the national exams from 2006 to 2011.

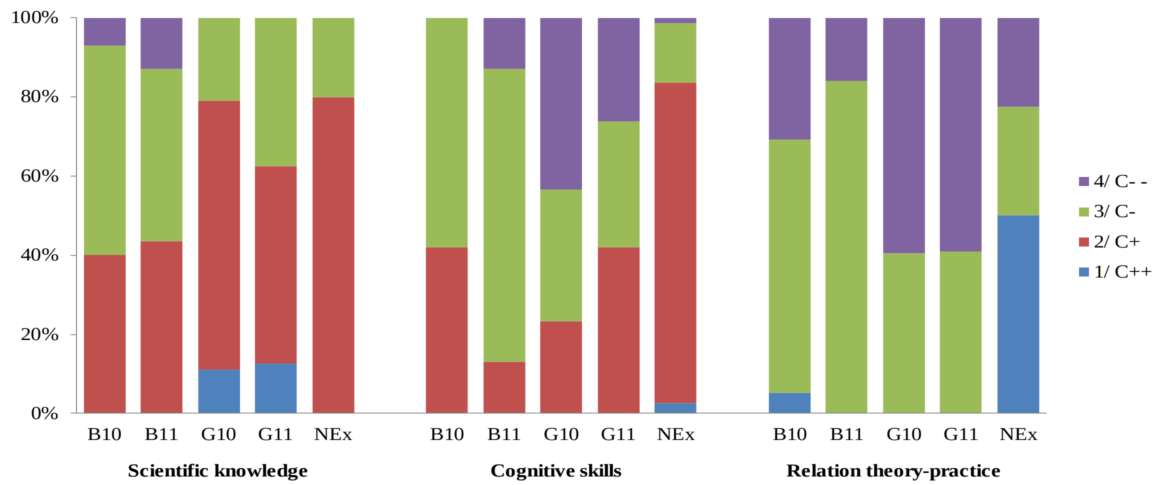

Figure 2. Conceptual demand of practical work in Portuguese Biology and Geology curriculum and external assessment at secondary school (*B10* 10th Biology syllabus, *B11* 11th Biology syllabus, *G10* 10th Geology syllabus, *G11* 11th Geology syllabus, *NEx* National Exams).

When Biology and Geology curricular subjects are compared, Biology shows more complex concepts and unifying themes (degrees 3 and 4) than Geology. The higher knowledge complexity in Biology practical work is especially given by the focus on cell theory and on evolution theory. In the case of Geology there are no units classified with degree 4 and there are units classified with degree 1. Simple concepts prevail in exams (degree 2). Degrees 1 and 4 (facts and unifying themes/theories, respectively) are absent in exams questions about practical work.

When the focus is the complexity of cognitive skills, it is Geology that places greater emphasis on complex cognitive skills of a high level (cognitive process of knowledge utilization – degree 4) when compared with Biology. The highest complexity of cognitive skills in Geology practical work is particularly related to the formulation of hypotheses, decision making, construction of models and research, organization and processing of information. Exams questions that mobilised science process skills were focused on the cognitive process of comprehension (degree 2).

With regard to the relation between theory and practice, most units were classified with C^{-} in Biology which correspond to the units that reflect a relation between the two types of knowledge with a focus on declarative knowledge. The data of Figure 2 also shows that C^{--} prevails in Geology syllabus which means that most units suggest a relation between declarative and procedural scientific knowledge, equal status being given to these two types of knowledge. In the exams half of the questions were classified with C^{++}. This classification refers to the second part of the respective instrument descriptor (Table 3), that is these questions only present procedural knowledge.

DISCUSSION AND CONCLUSIONS

The present study intended to appreciate the recontextualising processes that may have occurred between the messages expressed in the curriculum and the national exams of the Biology and Geology discipline in relation to the complexity of practical work. The results show the occurrence of discontinuities between the messages of the curriculum and the external assessment. Although the analysis is focused on the Portuguese educational system, the findings and methodologies of this study may be extended to other studies and may give a contribution to raising the level of conceptual demand of practical work in science education.

Through the analysis of the complexity of scientific knowledge and cognitive skills and the relation between theory and practice, it was possible to appreciate the level of conceptual demand of practical work expressed in the Official Pedagogic Discourse. When the discipline is taken as a whole (Biology and Geology together), the results evidence a considerable level of conceptual demand of practical work. However the separate analysis of the two subjects shows that Biology has a generally higher level of conceptual demand when compared with Geology. Practical work assessment in the national exams has a low level of conceptual demand, showing recontextualisation processes in the direction of lowering the level of the curriculum.

Within the curriculum have also occurred recontextualisation processes between the messages of practical work in Biology and Geology, considered as two separate components of the same discipline. One possible explanation for these discontinuities is related to the Ministry of Education selection of two different teams of authors to construct the curriculum of each one of the curricular areas. Each team of authors seemed to value different dimensions of *the what* and *the how* of pedagogic discourse. Some of these differences may also be related to the fact that Biology and Geology, although in Portugal are part of the same discipline, are epistemologically distinct curricular areas. In the case of the external assessment, the level of conceptual demand of practical work is lower than the level of the curriculum, namely in the case of the Biology syllabuses (the area most valued in the exams questions about practical work).

With regard to the complexity of scientific knowledge, the external assessment of practical work mainly values simple concepts. There is therefore a discontinuity between assessment and the curriculum practical work messages, where the Biology syllabuses give more emphasis to complex scientific knowledge (complex concepts and unifying themes/ theories). If science education is to reflect the structure of scientific knowledge then it should lead to the understanding of concepts and big ideas, although that understanding requires a balance between knowledge of distinct levels of complexity (Morais & Neves, 2016). Bybee and Scotter (2007) also present this aspect as a principle for the development of an effective science curriculum.

When the focus is the complexity of cognitive skills, the external assessment gives greater emphasis to simple skills, especially those involving the cognitive processes of comprehension. Similarly to scientific knowledge, in this case there is also a discontinuity in relation to the message of the Biology syllabuses in which complex skills prevail, particularly those associated with the cognitive process of analysis. The situation that better represents an efficient scientific learning, when practical work is implemented, is a situation where there is a balance between complex and simple cognitive skills. In this way, only when students develop simple skills, such as the memorization of certain facts and concepts, can they develop complex skills, such as applying these concepts to new situations (Geake, 2009).

In the case of the relation between theory and practice, there is also a devaluing of this relation when passing from the Biology and Geology curriculum to the national exams. For example while in the Biology syllabuses there is a relation between theory and practice, in the external assessment half of the practical work questions only focused procedural knowledge without relating it to declarative knowledge. The results of external assessment reinforces the results of other studies (e.g., Abrahams & Millar, 2008) that point out to the existence of a separation between theory and practice when teachers implement practical activities, particularly laboratory work.

In this study it was considered that the desirable situation with respect to the relation between theory and practice is a situation in which relations between declarative and procedural knowledge predominate, with more status being given to declarative knowledge in the relation. This is the situation that best represents an efficient scientific learning that is learning that is supported by the understanding and applying of science processes knowledge. The Biology syllabuses are closer to that situation.

The results of this study show that the external assessment presents a low level of conceptual demand, evidencing recontextualisation processes that reduce the level of the Biology and Geology curriculum. These are results of particular concern because external assessment tends globally to influence the curriculum in practice and specifically to condition textbook authors and teachers' practices. All knowledge and skills that are not the subject of external assessment tends to be ignored in pedagogic practice (e.g., Britton & Schneider, 2007).

The study highlights a major issue of educational systems that are not horizontally coherent i.e. systems where assessment is not aligned with the curriculum. As Wilson and Bertenthal (2006) refer, "to serve its function well, assessment must be tightly linked to curriculum and instruction so that all three elements are directed toward the same goals" (p. 4).

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