Draft Specification for Junior Cycle Science

Review and Critique

U
LISBOA
UNIVERSIDADE DE LISBOA

Instituto de Educação

Draft Specification for Junior Cycle Science

Review and Critique

(Commissioned by the National Council for Curriculum and Assessment, Ireland)

Authors: Cecília Galvão and Paula Serra

Cecília Galvão is a professor at the Institute of Education of the University of Lisbon. She has considerable experience in science education in Portugal. She coordinated the team responsible for the Specific Competences in Physical and Natural Sciences report, which integrated the national curriculum. She was also the coordinator responsible for *Curricular Guidelines for Physical and Natural Sciences for the 3rd cycle of Basic Education (ages 12-15)*, which was implemented in 2002/2003. She was the Portuguese coordinator of the European Project PARSEL. She coordinated a national project aimed at evaluating the national science curriculum. She is currently the Portuguese coordinator of the EU FP7 Project SAILS (*Strategies for Assessment of Inquiry Learning in Science*) coordinated by Dublin City University.

Email: cgalvao@ie.ulisboa.pt

Paula Serra is a secondary-level science teacher with extensive experience in teacher education, both in pre-service and in-service, and in the professional development of science teachers, particularly in the area of assessment in science. She worked in the Ministry of Education of Portugal, having collaborated in the development and monitoring of national policies on curriculum development. She was responsible for the project management of the *National Program of Teacher Training in Experimental Science Education* for primary school teachers. She participated in several research projects on intervention in schools related to science education.

Email: jprs@campus.ulisboa.pt

Lisboa, 20 October 2014

Address: Institute of Education, University of Lisbon
Alameda da Universidade
1649-013 Lisboa

Phone: + 351 21 794 36 33
Email: geral@ie.ulisboa.pt
Website: http://www.ie.ulisboa.pt

fac

EXECUTIVE SUMMARY

The position presented here focuses on the *Draft Specification for Junior Cycle Science* report (September, 2014), which was produced by the National Council for Curriculum and Assessment (NCCA). To clarify the goals and objectives, and the level to which these have been met, we also analysed the *Background Paper and Brief for the Review of Junior Cycle Science* (September, 2013).

In order to support our position, we reviewed a selection of reports and recommendations for science education (Table 1) from various internationally renowned publications. From this review, we identified the main challenges related to curriculum development facing science education in the 21st century. Other challenges, such as teacher training, schools' management and non-formal science education can determine the direction and effectiveness of science education for young people. However, as these challenges are not directly related to the curriculum, they were not considered in the present report.

Table 1- Reports and recommendations selected for review

Biological Sciences Curriculum Study (BSCS). (2007). *A decade of action: Sustaining global competitiveness. A synthesis of recommendations from business, industry, and government for a 21st-century workforce*. Colorado Springs, CO: BSCS.

Fensham, P. (2008). Science education policy-making: Eleven emerging issues. UNESCO.

European Commission (2004). *Europe needs more scientists: Report by the high level group on increasing human resources for science and technology in Europe*. Brussels: European Commission.

European Commission (2007). *Science education now: A renewed pedagogy for the future of Europe*. Brussels: European Commission.

European Commission/Eurydice (2011). *Science education in Europe: National policies, practices and research*. Brussels: EACEA.

National Research Council (2007). *Taking science to schools. Learning and teaching science in Grades K-8.* R. A., Duschl, H. A., Schweingruber, A. W., Shouse (Eds.). Committee on Science Learning, Kindergarten through Eighth Grade. Washington, DC: The National Academies Press.

National Research Council (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

OECD (2013). *PISA 2012 assessment and analytical framework*. OECD Publishing.

Osborne, J & Dillon. J. (2008). *Science education in Europe: critical reflections.* London: The Nuffield Foundation.

Royal Society (2014). *Vision for science and mathematics education.* London: The Royal Society Policy Centre.

In this report, we present challenges for curriculum development that were identified in the literature, we analyse the extent to which the *Draft Specification for Junior Cycle Science* (***JC Science Specification***) meets these challenges, and examine how the solutions presented in the specification converge with the recommendations of the experts.

Main conclusions

Challenge 1: Motivation for students to pursue science-related professions

The *JC Science Specification* recognises the importance of this purpose of science education and presents some solutions. Furthermore, it consistently addresses this challenge throughout all components of the document: aim, strands of knowledge, learning outcomes and assessment. The specification explicitly ensures that this aspect of the curriculum will be at the forefront for those responsible for its implementation and with transforming the school science in an attractive and motivating subject, in particular teachers, authors of textbooks, school leaders and teachers' educators.

Challenge 2: Scientific literacy/science for all

In line with the international research, the *JC Science Specification* recognises the need for students to be involved in the analysis and discussion of real socio-scientific issues, during which they can weigh up different interests and come to recognise the relevance of knowledge and scientific reasoning for solving problems, and for empowering citizens to analyse those problems. The specification document includes strategies for achieving those goals which are apparent at various levels: in the selection of content in each of the strands of knowledge; in the learning outcomes; in the assessment; and in the teachers’ guidelines.

Challenge 3: Nature of Science/how science works: the construction of authentic inquiry tasks

The *JC Science Specification* states that Nature of science is the unifying strand that permeates all the four contextual strands: Physical world, Materials, Biological world, and Earth and space. In doing so it recognises the centrality of inquiry in science learning. Establishing transversal components in the curricula without a clear specification of what should be taught and why, may cause the components to be forgotten by teachers and textbooks. Thus, we consider it important that the *JC Science Specification* has explained the components of the learning outcomes in the Nature of science strand. We highlight as a strong point of this component of the curriculum, which is in line with international recommendations, that it does not prescribe or favour any 'method' of scientific research; but instead gives relevance to the conditions that 'make science, science' (reliability, accuracy, precision, fairness, safety, ethics etc.). We also note the importance given to research focused on controversial issues, which require the intersection of information and diverse perspectives and the application of criteria of scientific validity, with the goal to facilitate rational and unbiased appraisal. Looking at the learning outcomes as a very important component of the curriculum, we propose some changes, showing the corresponding reasons.

Challenge 4: Selection and exploration of topics

The *JC Science Specification* is in line with international recommendations in this area. It establishes four large areas of scientific knowledge as contextual strands: Earth and space, Physical world, Materials and Biological world. For each of these areas of knowledge, it establishes a set of learning outcomes concerning a restricted set of concepts and theories, which reflect the main explanatory ideas of each area. We suggest the addition of one more item in the Energy element of the Biological world strand: 'Explain how matter and energy flow through ecosystems'.

Challenge 5: Learning outcomes

The definition of learning outcomes in the *JC Science Specification* is in line with international recommendations, as is the linking of learning situations for enacting competencies to scientific inquiry. However, to fully meet the curriculum objectives, we consider that some areas could be improved. We suggest the addition of a figure representing the integration of inquiry skills, attitudes and knowledge (the essence of learning outcomes). Similarly, in each table concerning the learning outcomes for the contextual strands (Earth and space, Materials, Physical world and Biological world) it should be possible to cross between the four elements that are associated to the Nature of science strand.

Challenge 6: Curriculum, teaching and assessment aligned with each other

The *JC Science Specification* is aligned with the international research in this area: the specification places a significant proportion of the summative assessment within the classroom, and places formative assessment in a prominent role for promoting scientific learning. In addition to this evaluation component, the *JC Science Specification* establishes a final assessment of an examination paper at a common level, with a weight of 60%. The *JC Science Specification* offers sensible and balanced solutions that take advantage of the benefits of each type of assessment (school work assessment and final assessment) and that compensate for the limitations of each one. In summary, the assessment model proposed by the *JC Science Specification* is consistent with the objectives of the curriculum and with international recommendations, and it contains solutions that promote the alignment of the curriculum implemented by teachers to the intentional curriculum.

CHALLENGES FACING SCIENCE EDUCATION IN THE 21ST CENTURY AND THE SOLUTIONS PROPOSED BY THE JC SCIENCE SPECIFICATION

Challenge 1: Motivation for students to pursue science-related professions

The social and economic development of countries depends on the development of science and technology. How can the curriculum and formal science teaching motivate students to pursue science-related professions?

In 2004, the report *Europe Needs More Scientists* (European Commission), recognised the low rate of people entering professions associated with Research & Development (R&D) in most European countries, when compared with rates in countries such as the United States of America or Japan. One of the reasons pointed to by the report was students' perceptions of school science. They perceive it as a difficult, boring and irrelevant subject, characterised by concepts and scientific facts far-related to the problems of today's world. This perception of school science hinders students from pursuing studies in the scientific area. Therefore, motivating students and encouraging their fascination with the beauty and importance of science must be one of the main purposes of the formal sciences education during compulsory school. The *JC Science Specification* recognises the importance of this aspect of science education and clearly includes it as one of its stated aims: 'to develop a sense of enjoyment in the learning of science, leading to a lifelong interest in science' (p. 7).

Some recommendations are made in the international literature in order to make school science more attractive and interesting for students, including

- contextualising scientific topics in problems and everyday situations
- associating technology achievements with the development of scientific knowledge
- showing how science can make a significant contribution in resolving many global problems such as world hunger, the over-exploitation of resources, emerging epidemics, climate change, etc.
- promoting a teaching practice framed by a model of Inquiry Based Learning (IBL), where students are challenged to discover solutions to problems using scientific practices.

The *JC Science Specification* consistently covers all these requirements throughout all components of the document: aim, strands of knowledge, learning outcomes and assessment. Therefore the specification explicitly ensures that this aspect of the curriculum will be at the forefront for those responsible for its implementation and for transforming school science into an attractive and motivating subject, in particular teachers, authors of textbooks, school leaders and teachers' educators.

Challenge 2: Scientific literacy/science for all

The contemporary world is increasingly shaped by problems created by unsustainable overexploitation of natural resources, which may endanger the balance of the planet and enhance economic and social imbalances. Many of these problems involve a scientific and technological component. How can the curriculum and science education contribute to the formation of informed *and critical citizens, who are able to position themselves and to make decisions concerning these problems?*

Today’s global problems are characterised by enormous complexity and often require difficult decisions. Every day, citizens are bombarded with information and conflicting opinions through the media and the internet, making it difficult to distinguish bias and to form a judgment on the reliability or trustworthiness of any particular position.

Considering that only some of the students who attend compulsory education will continue studies in a scientific area, many experts argue that science education during the primary and junior cycles should have as its main purpose the preparation of informed and critical citizens, who are able to make informed and reasonable decisions, and who can contribute to a more balanced and fair world.

There is a general consensus about the need for students to be involved in the analysis and discussion of real socio-scientific issues, during which they can weigh up different interests and through which they come to recognise the relevance of knowledge and scientific reasoning for solving problems, and for empowering citizens to analyse those problems.

The *JC Science Specification* is aligned with this international consensus, defining as a second aim the need 'to develop scientific literacy and apply this in cognitive, affective and psychomotor dimensions to the analysis of science issues relevant to society, the environment and sustainability' (p. 7).

As it is vital not only to articulate educational aims, but to define the strategies for achieving them, we analysed the implementation solutions proposed in the specification. These are seen at various levels:

- in the selection of content in each of the strands of knowledge, when it suggests that the treatment of fundamental scientific ideas (Materials, Earth and space, Physical world and Biological world) should lead, for instance, 'to understand science-related challenges, such as environmental sustainability', and 'the impact of humans on the natural world'
- in the learning outcomes, when it seeks to convey the idea that real problems have a complex and interdisciplinary nature, proposing an integrated approach to topics, where in addition to the key concepts (building blocks), students are encouraged to consider transversal elements, such as energy, sustainability and systems and interactions
- in learning outcomes, when the specification explicitly considers the transversal element 'Science in society'
- in the assessment, when it establishes 'issues investigation' as an evaluation method, using tasks 'to assess students’ abilities to research socio-scientific issues, collect, analyse and draw evidence-based conclusions about secondary data and information, and to make appropriate recommendations'
- in the teachers’ guidelines for assessment, through the establishment of 'features of quality', which are 'criteria that will be used to assess the pieces of student work... in three aspects of a scientific investigation: initiating research, reporting, and evaluating. For each aspect, there are five hierarchical sets of features of quality.' (p. 100).

Challenge 3- Nature of Science/how science works: the construction of authentic inquiry tasks

Science is characterised by a body of specific knowledge and 'ways of thinking and doing' that must satisfy certain criteria of validity. Thus, science teaching should allow students, not only to construct scientific knowledge, but also to be introduced to the scientific culture, through students' immersion in its main methods and practices. How can science curriculum and teaching move from the excessive weight that has been given to the content of science to a more authentic science (and a more relevant one from the point of view of students), one that captures the variety of methods used by science and its main reasoning schemes, the criteria used for assessing scientific validity, and the social practices which affect the way science is communicated and argued?

For many years now, the involvement of students with activities that mirror the methods developed by scientists (authentic inquiry) has been one of the objectives of science education. Wellington (1998), Chinn and Malhotra (2002), Duschl (2003, 2008) do a retrospective analysis of the debate around inquiry and practical work in science classes and they provide proposals for circumventing the difficulties that have arisen in meeting this challenge. Combining the ideas of these authors, we believe that inquiry in the framework of science teaching has been guided by two continuums which often assume dichotomic characteristics. At one extreme of the CP (content-process) continuum is science education overly-centred on content, with science education focused on processes (process approach), thus devaluing scientific knowledge, at the other. The DP (Discovery-Prescription of research) continuum has at one end the idea that students can achieve knowledge by themselves through a process of interaction with the environment; opposing this is the idea that scientific research is dominated by control of variables within experimentation and by induction (i.e. the experiments lead to theory). This prescriptive idea of scientific research has been coupled with the restrictive circumstances of practical work in the classroom. So practical work involves a restrictive set of activities that are selected not because they can be translated to authentic inquiry, but simply because

- they can be carried out within the technical and material limitations of a school lab and during the science class
- they fit in the format of inquiry as conceived by the official curriculum
- they can be evaluated through a standardised and unique model, which allows comparisons among students (Wellington, 1998).

To work around the limitations of these models of inquiry, and starting from the idea that 'science distinguishes itself from other ways of knowing by appealing to evidence that is deemed objective by its practitioners and then using the evidence to put forth testable explanations', Duschl (2003, 2008) suggests that inquiry as conceived in science curriculum and science education should move to a new continuum, called EE (Evidence-Explanation), which includes:

1. Selecting or generating data to become evidence.
2. Using evidence to ascertain patterns of evidence and models.
3. Employing the models and patterns to propose explanations.

This model of inquiry will achieve a better balance between conceptual, epistemic and social goals of science education, by means of balanced curricula that:

- Are not dominated by a single model of practical work; instead these curricula should propose diversified activities that promote the integration of knowledge, skills and attitudes and reflect the diversity of projects developed by scientists.
- Allow the involvement of students, at least once a year, in a genuine long-term thorough investigation (research project), that does not have a prescribed format. During this research project, students would consider and make decisions about how to generate, select and analyse data in order to constitute evidence and examine how evidence, in conjunction with theoretical knowledge, could be used to propose scientific explanations.
- Make reports of past and contemporary investigations available to students. These reports would allow students' appreciation of the sophistication of investigative methods and of new techniques of observation and data collection. These second-hand data should be used to engage students in conversations (discussion, debate, construction of models, data representation, schemas, writing) during which they can recognise the interaction between data, methods, data representations, conceptual models, evidence and explanatory theories.
- Allow making students' thinking visible, so that the teacher can interpret students' difficulties and provide appropriate feedback, promoting their progression in learning.
- Facilitate students' use of ICT as a way to access simulations and real scientific databases, as well as for facilitating data representation and processing.
- Allow the students to engage with some contemporary controversial issues such as cloning and climate change. This involvement should enable students to question available data, how the data was retrieved and by whom, different interpretations of the same data, the quality and limitations of the research, the coverage given by the media and the bias of the people involved.

How does the *JC Science Specification* answer to this challenge?

The *JC Science Specification* states that Nature of science is the unifying strand that permeates all the four contextual strands: Physical world, Materials, Biological world, and Earth and space. In doing so it recognises the centrality of inquiry in science learning. The curriculum does not specify any content linked to the Nature of science strand in itself, and states that 'its learning outcomes underpin the activities and content in the contextual strands. The learning outcomes are pursued through the contextual strands as students develop their content knowledge of science through scientific inquiry.' (p. 13) In fact, inquiry underlies all scientific content and typically requires knowledge integration across several areas of science and ways of reasoning.

The *JC Science Specification* clarifies that this component focuses 'on how science works, carrying out investigations, communicating in science, and developing an appreciation of the role and contribution of science and scientists to society' (p. 13).

Establishing transversal components in the curricula without a clear specification of what should be taught and why, may cause them to be forgotten by teachers and textbooks. Thus, we consider it important that the *JC Science Specification* has explained the components of the learning outcomes in the Nature of science strand. These components are: Understanding about science, Investigating in science, Communicating in science and Science in society (p. 19). These four elements cover the main activities undertaken by scientists (Investigating in science and Communicating in science), they allow students' understanding of the scientific enterprise (Understanding about science) and they recognise the importance of science in society (Science in society). These components can be a way to generate interest in science throughout students' lives, as we have already seen.

We highlight as a strong point of this component of the curriculum, which is in line with international recommendations, that it does not prescribe or favour any 'method' of scientific research; but instead gives relevance to the conditions that 'make science, science' (reliability, accuracy, precision, fairness, safety, ethics etc.) and stresses common practices of investigations (e.g. distinguishing questions that are possible to investigate scientifically, designing investigations, producing data, identifying patterns or anomalies in data, drawing and justifying conclusions, reviewing).

We also note the importance that the specification gives to research focused on controversial issues which require the intersection of information and diverse perspectives and the application of criteria of scientific validity, with the goal to facilitate rational and unbiased appraisal.

Given the key nature of this strand in the curriculum, we consider it relevant to analyse in detail the learning outcomes established for each element (*JC Science Specification,* p. 19) and to evaluate the extent to which they are suitable and lead to the implementation of the recommendations presented. From our analysis, we propose the following changes, shown in bold below with the corresponding reasons:

Strand one: The nature of science		
Elements	Learning outcomes *Students should be able to*	Reasons
Understanding about science	1. appreciate how scientists work and how scientific ideas are modified over time*; **recognise that the aim of science is to propose explanations about the natural world guided by knowledge, evidence and reasoning; recognise that science, in each historical moment, is shaped by the expectations and beliefs of society**	Understanding the science scope and its aim helps students to investigate accurately, and to recognise the questions and methods that are appropriate in science investigation (the next element). Science is not an isolated enterprise. Science influences society (Science in society), but it is also shaped by society.

Investigating in science	2. recognise questions that are appropriate for scientific investigation, pose testable hypotheses, and evaluate and compare strategies for investigating hypotheses	Moved from Understanding about science: this is part of doing scientific investigation.
	3. design, plan and conduct investigations; explain how reliability, accuracy, precision, fairness, safety, ethics, and selection of suitable equipment have been considered*	
	4. 4. produce **or select** data (qualitatively/quantitatively), critically analyse data to identify patterns and relationships, identify anomalous observations, draw and justify conclusions *; **mobilise (or identify where to search for) the scientific knowledge needed to interpret evidence, activating ways of reasoning appropriate to the construction of an explanation**	Reading and analysing investigations made by others is part of doing scientific investigation (bibliographic research). Differentiating and coordinating between theory and evidence is central to scientific reasoning.
	5. review and reflect on the skills and thinking used in carrying out their scientific investigations and apply their learning and skills to solving problems in unfamiliar contexts; **discuss and debate investigations made by others (second-hand data), showing that they understand the dialectic between problems, methods, techniques of gathering data, evidence and theoretical models**	Dealing with second-hand investigations is, sometimes, the only way of introducing students to 'real science' and overcoming the limitations of the school laboratory.
Communicating in science	6. conduct research relevant to a scientific issue, evaluate different sources of information, understanding that a source may lack detail or show bias* 7. organise and communicate their research and investigative findings in a variety of ways fit for purpose and audience, using relevant scientific terminology and representations * 8. evaluate media-based arguments concerning science and technology*	No changes
Science in society	9. research and present information on the contribution that scientists make to scientific discovery and invention, and its impact on society* 10. appreciate the role of science in society, and its personal, social and global importance.*	No changes

Challenge 4: Selection and management of scientific content

In a field where knowledge is constantly evolving at an accelerated rate, how to select which knowledge is important for making an individual scientifically literate? Science curricula have been characterised by creating different subjects related to the 'classical sciences' of biology, chemistry and physics; however, real problems with a scientific basis have an increasingly interdisciplinary nature. How can the curriculum and teaching create a space and solutions for an interdisciplinary exploration of subjects/scientific problems, without alienating the knowledge and methods specific to each discipline?

In general, international recommendations for science education policies call attention to the need to develop a curriculum around fundamental scientific ideas, and to avoid the proliferation of irrelevant scientific topics which do not significantly contribute to students' learning. This proliferation leads to curricula which are centred on content and which are often too ambitious to be fully covered by teachers. Science education is in strong danger of 'being excessively factual because of the explosion in scientific knowledge and the 'adding-on' of topics to an already excessive content base. And, to add to all this, the measures of assessment of student achievement have been largely confined to the regurgitation of information.'(EC, 2004, p. xi).

Once the key ideas for each scientific area are identified, the scientific concepts should be carefully selected throughout the years of schooling, in order i) to facilitate understanding of these key ideas in a progressively deeper way; and ii) to establish a bridge with more recent and relevant topics, considering the point of view of research as well as of economy and society. Although few articles identify the most relevant scientific topics from a social and economic point of view, the report *A Decade of Action: Sustaining Global Competitiveness: A Synthesis of Recommendations from Business, Industry, and Government for a 21st-century Workforce* (BSCS, 2007) identifies the following as key economic sectors within the scientific domain:

- aerospace
- biotechnology
- energy
- hazard mitigation
- health
- information and communication
- nanotechnology
- pharmaceuticals
- resources.

Therefore, these topics should be explored during compulsory schooling by students. Another important issue related to the scientific content concerns the balance between the respect for the individuality of each area of knowledge (with its own concepts, practices and ways of reasoning) and the integration and interdisciplinary exploration required by most real-world problems.

The *JC Science Specification* is aligned with these international recommendations. It establishes four large areas of scientific knowledge as contextual strands: Earth and space, Physical world, Materials and Biological world. Then, for each of these areas of knowledge, it establishes a set of learning outcomes concerning a restricted set of concepts and theories, which reflect the main explanatory ideas of each area. We suggest the addition of one more item in the Energy element of the Biological world strand: 'Explain how matter and energy flow through ecosystems'.

These scientific ideas are essential for understanding some of the technological advances which have great economic impact in contemporary society, such as biotechnology, information and communication technologies, nanotechnology, etc. The *JC Science Specification* leaves room (and in the learning outcomes, it sometimes makes a direct appeal) to establish bridges between fundamental knowledge and its applications; this is relevant from the point of view of scientific literacy.

The fact that each strand is contextually permeated by common elements (Systems and interactions, Energy and sustainability) creates cohesion between the different areas of knowledge and facilitates interdisciplinary approaches.

Challenge 5: Learning outcomes

Learning outcomes are central to any official curriculum document, as they constitute the benchmark for structuring teaching and assessment. Thus, it is important that they mirror the goals of the curriculum and its guidelines. How can one write clear and objective learning outcomes that reflect intended learning?

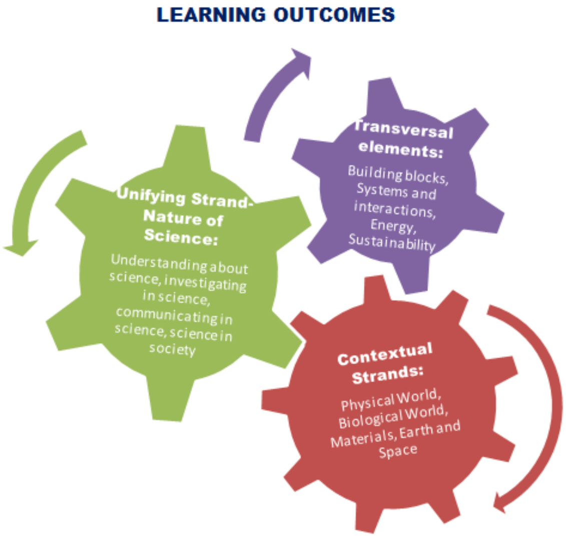
Albeit with different designations (standards, objectives, performance, expectations, learning outcomes), virtually all contemporary curricula (and international assessments, such as PISA) pursue the idea that students' learning must have a systemic character, so that in a concrete situation, students are capable of simultaneously mobilising knowledge, skills and dispositions or attitudes. This way of understanding learning has two consequences in terms of curriculum development. On the one hand, curricula were designed for developing competences (a systemic concept that mobilises a vast set of resources from different domains) and, on the other hand, curricula were conceptualised as organised around learning situations, which have the potential for promoting the mobilisation and development of those competencies. 'It is only in situation that a person develops his/her competence, and therefore the situation is the source of competence. Furthermore, it is only by dealing effectively with this situation that a person can be declared competent' (Jonnaert et al., 2006, p. 4).

The *JC Science Specification* is aligned with the research recommendations, describing learning outcomes as 'statements that describe the understanding, skills and values students should be able to demonstrate after a period of learning' (p. 18). Furthermore, learning situations for enacting competencies are connected to scientific inquiry: 'The learning outcomes are pursued through the contextual strands as students develop their content knowledge of science through scientific inquiry' (p. 13).

However, to achieve these objectives, and give an accurate interpretation of the intentional curriculum, we recommend some improvements.

While Figure 2 on page 15 clearly illustrates the integrated nature of the strands of knowledge (with the contextual elements that cut-across all strands), there is no corresponding figure representing the integration of inquiry skills, attitudes and knowledge (the essence of learning outcomes). The following figure is a simple example of how an idea can be transmitted when one defines the concept of learning outcome (p. 18).

Similarly, in each table concerning the learning outcomes for the contextual strands (Earth and space, Materials, Physical world and Biological world) it should be possible to cross the four elements (practices and scientific processes) that are associated with the Nature of science strand. Thus, whenever a teacher consults a particular contextual strand, he/she would always have access to the inquiry skills that cross the different concepts. However we recognise that this can be difficult to represent graphically.



Despite these suggestions, we recognise that there is no danger that inquiry skills are devalued by teachers during teaching, as assessment organisation (as will be seen in next topic) ensures that this will not happen. Another more specific suggestion concerns the concept of 'Expectations for students', defined as 'an umbrella term that links learning outcomes with annotated examples of student work in the subject or short course specification' (p. 18). An illustration by means of an example does not modify a concept: rather it clarifies the concept; so we wonder whether 'Expectations for students' and 'Learning outcomes' are synonymous or different concepts. Therefore, we emphasise the importance of clarifying this.

Challenge 6: Curriculum, teaching and assessment aligned with each other

Despite assessment having been recognised as part of the teaching-learning process and as having a formative character, teachers and assessment systems have put assessment within a temporal line, according to which one first teaches, and then one assesses. In addition, it has not been easy to find solutions for assessing performance and reasoning, namely in contexts of practical work. What kind of curricular solutions facilitate teachers' empowerment for aligning curriculum, assessment and teaching?

Few education topics have gained such extended consensus as the recognition of the need for aligning curriculum, teaching and assessment and the recognition of the key role played by teachers' assessment (in particular formative assessment) in achieving this alignment. This consensus results, in part, from the existence of strong scientific evidence illuminating the relationship between formative assessment and improved learning (Black & Wiliam, 1998).

The *JC Science Specification* is aligned with this consensus, as it places a significant proportion of the summative assessment within the classroom (40% for the school work component) and places formative assessment in a prominent role for promoting scientific learning: 'Providing focused feedback on their learning to students is a critical component of high-quality assessment and a key factor in building students' capacity to manage their own learning and their motivation to stick with a complex task or problem. Assessment is most effective when it moves beyond marks and grades to provide detailed feedback that focuses not just on how the student has done in the past but on the next steps for further learning' (p. 25). In addition to this evaluation component, the *JC Science Specification* establishes a final assessment of an examination paper at a common level, with a weight of 60%. Initially, the final assessment and marking scheme for grading purposes will be prepared by the State Examinations Commission.

Concerning the advantages and disadvantages of performance assessment in the science classroom and large-scale standardised assessment, the report *Science Education in Europe: National Policies, Practices and Research* (EU/Eurydice, 2011) mentions that 'the focus tends to be on the test content rather than on curriculum standards or objectives' and 'what is not tested might not get teachers' full attention or might not be taught at all' (p. 90). So, standardised assessments 'usually fail to assess the wide range of skills students need to be truly successful in science' and 'the skills and knowledge tested tend to be at a lower level than curriculum requirements' (p. 91).

In a subject where inquiry and practical work are central aspects of teaching and learning, assessment of performance becomes particularly relevant. By relying on alternative assessment techniques, such as observation, portfolios, essays, reports, etc., assessment of performance enables the assessment of practical skills (such as observation, measurement, experimentation, research) that cannot be addressed by more or less standardised written tests. However, this type of assessment for summative purposes also presents some limitations, mainly related to issues of validity and of comparison between students' performances.

The *JC Science Specification* offers sensible and balanced solutions that take advantage of the benefits of each type of assessment (school work assessment and final assessment) and that compensate for the limitations of each one.

a) By focusing school work assessment exclusively on the practical work and on the learning outcomes of the Nature of science strand, it ensures that teachers will effectively include this dimension during teaching, i.e., it ensures that teaching will not focus excessively on content.

b) By contemplating the possibility of using different forms of assessment (note, hand-written/typed report, computer-generated simulations, multimodal presentation, webpages, model building, podcasts), it enables the adequacy of the data collection techniques to learning, considering its variety and complexity.

c) By pointing out as objectives of the school work assessment the development of research using first-hand data and focused on socio-scientific issues, it ensures that all elements of the Nature of science strand are included in teaching and that the curriculum is fulfilled; i.e., students will have the opportunity to learn science, about science and about the impact of science in the contemporary world.

d) The curriculum deals with the limitations related to the validity of performance assessment by attributing the highest percentage of assessment (60%) for the 'final assessment'. Consisting of a written test (conducted and marked by the teacher) and being focused on understanding of concepts, the final assessment allows the construction of more standardised tests. Under the strict point of view of the validity of the assessment, there would be advantages in transforming this test into an external large-scale assessment. However there are other aspects to be taken into account when making such a decision, namely ideological and practical issues, such as economic viability, and whether or not other school subjects are externally assessed. The definition of weightings for the different components of the assessment, 'during practical work' (10%) and 'scientific research' (30%) as well as the establishment of weightings for the classification of various components of the 'scientific research report' and of the 'issues investigation', also contribute to making assessment homogeneous at the national level, facilitating comparison between students' performance.

Assessment carried out by teachers in the classroom is a difficult task. Whether it is formative or summative, it relies on teachers' ability to use specific techniques for collecting evidence of students' scientific learning and their ability to interpret this evidence as the basis of criteria to rank students according to level of performance. The interpretation of the evidence of learning is essential for a fair judgment concerning value (in the case of summative assessment), and for the provision of appropriate and potentially effective feedback for promoting students' scientific learning (in the case of formative assessment). Therefore, it is particularly important that teachers are provided with guidelines for collecting evidence about learning as well as for interpreting it. These guidelines are considered fundamental by the previously mentioned European report on science education (EC/Eurydice, 2011), which simultaneously recognises that only half of the European countries provide specific guidelines for assessing science learning.

The JC Science Specification states that 'teachers and schools will have access to an Assessment and Moderation Toolkit with learning, teaching and assessment support material, including: ongoing assessment, planning for and designing assessment, assessment tasks for classroom use, judging student work – looking at expectations for students and features of quality, reporting to parents, thinking about assessment: ideas, research and reflections and glossary of assessment and moderation terms' (p. 25).

In addition to this kit, the *JC Science Specification* defines 'features of quality' which are the 'criteria that will be used to assess the pieces of student work' (p. 96). These criteria are of fundamental importance as they work as the framework for interpreting evidence of students' learning. However, given the diversity of tasks of inquiry that can be implemented in the classroom, we suggest that these criteria should be monitored in the first years of implementation of the curriculum, with a view to adjustment, if necessary.

In summary, the assessment model proposed by the *JC Science Specification* is consistent with the objectives of the curriculum and with international recommendations, and it contains solutions that promote the alignment of the curriculum implemented by teachers to the intentional curriculum.

References

In addition to a list of reports reviewed (Table 1) the following references are noted.

Black, P. & Wiliam, D. (1998). *Inside the black box: Raising standards through classroom assessment.* Phi Delta Kappan. *80*(2), 139-148.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218.

Duschl, R. (2003). Assessment of inquiry. In J.M. Atkin & J. Coffey (Eds.), *Everyday assessment in science classrooms*. Washington, DC: NSTA Press.

Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education*, *32*(1), 268-291.

Jonnaert, P. et al. (2006). *Revisiting the concept of competence as an organizing principle for programs of study: From competence to competent action*. Geneva: International Bureau of Education, IBE/UNESCO.

Wellington, J. (Ed.). (1998). *Practical work in school science: Which way now?*. London: Routledge.