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Responsible research and innovation indicators for science education assessment: how to measure the impact?

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ABSTRACT

The emerging paradigm of responsible research and innovation (RRI) in the European Commission policy discourse identifies science education as a key agenda for better equipping students with skills and knowledge to tackle complex societal challenges and foster active citizenship in democratic societies. The operationalisation of this broad approach in science education demands, however, the identification of assessment frameworks able to grasp the complexity of RRI process requirements and learning outcomes within science education practice. This article aims to shed light over the application of the RRI approach in science education by proposing a RRI-based analytical framework for science education assessment. We use such framework to review a sample of empirical studies of science education assessments and critically analyse it under the lenses of RRI criteria. As a result, we identify a set of 86 key RRI assessment indicators in science education related to RRI values, transversal competences and experiential and cognitive aspects of learning. We argue that looking at science education through the lenses of RRI can potentially contribute to the integration of metacognitive skills, emotional aspects and procedural dimensions within impact assessments so as to address the complexity of learning.

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Responsible research and innovation; science learning; assessment indicators; engagement; young people

Introduction

Science education is crucial for boosting a more critical and democratic citizenship able to deal with current complex socio-environmental challenges in responsible ways (EU, 2015; Klassen, Kupper, Rijnen, Vermeulen, & Broerse, 2014). This is widely recognised by the responsible research and innovation (RRI) approach, a paradigm born from academic discussions one decade ago, which is currently permeating European policies through the Horizon 2020 funding programme (Owen, Macnaghten, & Stilgoe, 2012). RRI entails a dynamic and iterative process by which all the stakeholders involved in the research and innovation practice become mutually responsive and share responsibility regarding both outcomes and process requirements so as to align research and innovation

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agendas with societal needs and concerns (Arnaldi & Gorgoni, 2016). Within this approach, science education has been identified as a key policy agenda. Under the lenses of RRI, contemporary science education should foster students' engagement, critical thinking and reflexivity about science and scientific practice, as well as enhance social and personal skills, and embed social and ethical principles in the educative process (EU, 2015).

To ensure the proper inclusion of such RRI learning outcomes and process requirements in science education practice, it is crucial to develop impact assessment frameworks directly and effectively addressing these aspects. The strategic value of assessing RRI in the context of science learning lies not only in identifying and justifying critical thinking and other learning outcomes, but also in shaping and potentially enhancing the possibilities of the learning process itself (Millar, 2013). This is encompassed within the broader need for having clear understandings of the implications of RRI in different contexts of action (e.g. formal and informal educational settings), so as to develop rigorous monitoring and assessment methods of RRI impacts (Strand et al., 2015). As the Expert Group on Policy Indicators for RRI remarks, 'it is difficult to specify a precise, valid and robust indicator for something that is imprecise and changing' (Strand et al., 2015, p. 9). Due to the emerging and challenging nature of the RRI approach, academic research looking at science education assessments under this paradigm is still scarce.

In order to address this gap, we propose an analytical framework identifying RRI-related assessment criteria for science education. We then apply such framework to explore a set of empirical studies assessing the impact of science education activities with young people, with the aim of identifying assessment indicators contributing to the operationalisation and monitoring of RRI in science education with students. With this purpose in mind, the following questions guided our research: (1) How are RRI learning outcomes and process requirements addressed within the field of science education through the assessment methods explored? (2) How can we systematise the inclusion of RRI criteria and indicators within science education assessment methodological frameworks? Indeed, the definition of RRI-related assessment criteria and indicators can help science education researchers and practitioners not only to ground the concept of RRI, but also to identify a diversity of learning goals and process requirements, potentially enhancing young people's scientific learning.

In what follows, this paper briefly introduces the notion of RRI in science education and proposes an analytical framework for its assessment. It then uses this framework to consider a set of empirical studies featuring science education assessments. As a result, we identify a set of 86 assessment indicators relevant in the context of science education under the lenses of RRI, informed both by conceptual and empirical insights. Finally, we discuss the potential contributions of the resulting RRI analytical framework for science education assessment to current methodological developments aiming at better capturing learning complexity and multidimensionality.

What does RRI mean in the context of science education?

Under the lenses of RRI, science education focuses on fostering young students' engagement with science and their empowerment as responsible and active citizens. To achieve this, RRI promotes critical thinking and reflexivity about science and scientific practice, the development of transversal competences relevant to scientific thinking and the embedding of social and ethical principles in the educative process, such as students' inclusiveness or the social relevance of the topics approached (EC, 2012a; Klassen et al., 2014). The RRI approach implies, thus, a shift in the focus of science education outcomes from learning discrete scientific facts to understanding how to apply science learning to different and new situations, and stimulating curiosity, scientific thinking and the understanding of the nature of science (EU, 2015). That shift includes cognitive aspects of learning that go beyond the assimilation of basic knowledge to imply high-order thinking and metacognitive skills (EU, 2015; Klassen et al., 2014), emphasising as well the relevance of experiential aspects. Indeed, students' engagement with science is a key learning outcome, which places attention on students' attitudes towards and perceptions about science, but also on the feelings, emotions and embodied insights generated, expressed or processed through the experience of learning.

Furthermore, RRI represents an umbrella term that both agglutinates and extends aspects from different educational trends and approaches that gained importance in science education in the last decades, such as those based on student-centred, active pedagogies (Bell, Urhahne, Schanze, & Ploetzner, 2010). Inquiry-based learning (Marques et al., 2014; Minner, Levy, & Century, 2010), twenty-first century skills (NRC, 2012; P21, 2007), or life-long learning (EC, 2012b) are among these emerging approaches fitting within the RRI paradigm, due to their emphasis on developing students' critical thinking, creativity, cooperative skills, learning autonomy and other transversal competences (EC 2006).

If these broader outcomes are to be achieved, then relevant science education processes should be designed and developed. In this sense, an educational process under the lenses of RRI should engage the diversity of students' profiles in an inclusive process and cover a wide range of disciplines, embedding critical reflexivity both about the scientific issues approached and their potential impacts – as well as about the learning process itself. It should also focus on real-life challenges and be honest about uncertainty in science and the limitations of scientific knowledge and practice, and be able to respond to students' perspectives, values and concerns and to different implementation contexts (EU, 2015; Klassen et al., 2014).

The integration of such process requirements and learning outcomes in science education requires their careful operationalisation in education assessments. The increasing recognition of the importance of assessment to contemporary science education 'has catalysed research, development, and implementation of new methods of data collection along with new ways of judging data quality' (NRC, 1996, p. 76). This is reflected in the increasing emphasis on assessment for learning approaches within science education, in which assessment is perceived as intrinsic for effective science instruction (Wiliam, 2011).

A framework for assessing RRI in science education

Taking into account the RRI learning outcomes and process requirements previously identified in the literature, we propose an evolving analytical framework that includes a set of interlinked criteria providing a systematic approach to data collection, analysis and interpretation (Heras, Ruiz-Mallén, Berrens, & Lemkow, 2016). Such criteria are organised around four key learning dimensions of RRI that integrate eleven process requirements and learning outcomes. They represent different levels of complexity: (i) basic cognitive learning aspects, (ii) experiential learning aspects, (iii) transversal competences and (iv) RRI values (see Table 1).

Table 1. Analytical framework for the assessment of RRI criteria addressing RRI process requirements and learning outcomes.

RRI learning dimension	RRI learning outcome and/or process requirement	Assessment criteria and operative definition
Basic cognitive aspects of learning	**Acquisition of knowledge:** ability to acquire tacit and conceptual knowledge about science and scientific topics	*Acquisition of conceptual knowledge:* recall and retention of science concepts and information, learning of facts, perceived knowledge gains or conceptual change
		Acquisition of tacit knowledge: acquisition and assimilation of implicit and procedural knowledge about science and related topics
Experiential aspects of learning	**Feelings and emotions:** experiential aspects related to emotional, body and spatial awareness arising during or as a result of the educational process	*Enjoyment:* feelings of pleasure caused by doing or experiencing something the person likes
		Emotional awareness and reflexivity: student's capacity to identify or express emotions associated with the topics addressed and to reflect upon and through their emotional responses
		Body and spatial awareness: body movement and expressiveness, sensual awareness, relation with the physical space
		Empowerment and sense of belonging: sense of ability to do things and feeling of acceptance as part or member within a group or environment
	Attitudes and perceptions: predispositions and understandings towards science and/or the scientific issues approached and the learning experience	*Attitudes towards science and the scientific issues approached:* participants' predisposition or tendency to respond positively or negatively towards science concepts, ideas and topics
		Perceptions of science and the scientific issues approached: participants' organization and interpretation of science concepts, ideas and topics
Transversal competences	**Learning to learn:** ability to pursue and organize one's own learning, in accordance with one's own needs, and awareness of learning methods and opportunities	*Understanding the value of learning:* awareness of one's learning process based on the experience and values developed through engagement with science education practices
		Learning autonomy: ability to pursue and persist in science learning, to organise one's own learning, including through effective management of time and information, both individually and in groups
		Reflective thinking: ability to gain, process and assimilate new scientific learning and related life experiences through reasoned thinking and/or discussion, in order to use and apply them in a variety of contexts
	Social and civic competences: personal, interpersonal and intercultural competences and all forms of behaviour that equip individuals to participate in an effective and constructive way in social and working life	*Communication skills:* ability to communicate ideas about science effectively by using verbal, visual and written tools as well as body language
		Collaborative skills: behaviours that help two or more people work together in the science learning process
		Respect for society and environment: behaviours that favour acceptance and respect for others, as well as environmental awareness
		Informed and reasoned decision-making: ability to analyse, evaluate, and make sound and informed decisions when transferring scientific knowledge into action
		Ability to resolve conflicts: ability to approach conflict in a constructive manner through managing the process instead of negating it

(*Continued*)

Table 1. Continued.

RRI learning dimension	RRI learning outcome and/or process requirement	Assessment criteria and operative definition
	Sense of initiative and entrepreneurship: ability to turn ideas into action that involves creativity, innovation and risk-taking, as well as the ability to plan and manage projects in order to achieve objectives	*Entrepreneurship*: ability to turn ideas into action when learning science, including innovation and risk-taking
		Self-confidence and esteem: perceived capability to effectively accomplish a certain level of performance in science learning, including self-esteem
		Ability to plan and manage projects: ability to plan and manage science projects in order to achieve objectives
RRI values	**Inclusiveness of all participants:** reaching diverse students' profiles and learning styles and inclusion of different relevant stakeholders	*Balanced participation*: inclusiveness and involvement of all participants, making sure that each one has the opportunity to contribute to the process in an active way
		Fostering dialogue among participants: capacity of the process to build learning upon participants' mutual exchange of ideas and opinions so as to integrate different perspectives and work together
	Gender equality: being sensitive to gender differences and critically approaching and managing gender aspects in science and research	*Gender balance in participation*: participation differences according to gender
		Critically approaching gender issues: acknowledging and critically reflecting about gender differences and their causes and implications
	Engagement: enhancing students' active involvement in science and scientific research	*Emotional engagement:* active involvement in the activity or project, related to intrinsic motivation, affective reasons and/or interest
		Cognitive engagement: sustained, engaged attention during a task or process requiring mental effort
	Creative and critical thinking: boosting students' ability to actively conceptualise, analyse, apply and evaluate information and knowledge	*Questioning and reframing:* promotion of understanding through questions that allow students complex thinking and the possibility to see the issues approached in new or different ways
		Systems thinking: holistic approach to analysis that considers the interactions between the constituents of a system
		Connecting topics with experience: contextualisation of the issues approached within their broader societal context and connection with participants' experience
		Seeking other points of view: consideration of different perspectives and points of view in participants' discourse
	Integration of ethical issues: ensuring open, responsive and transparent educational processes and reflecting about ethical aspects of science and research	*Understanding of the nature of science (NOS):* key principles and ideas, which provide a description of science as a way of knowing, and the characteristics of scientific knowledge
		Social relevance of topics addressed: degree to which the scientific issues approached are connected to relevant broader social contexts and challenges
		Participants acceptance of process/ outcomes: degree to which participants accept and feel ownership of the different learning outcomes and processes involved in the activity
		Connecting scientific topics with values: identification and exploration of the diverse values and normative aspects behind scientific practice and knowledge

Implementation of the framework

Review of assessment studies

Based on the proposed analytical framework, we thoughtfully reviewed a selection of academic articles and book chapters on the empirical assessment of specific science education activities. Specifically, we examined the operationalisation in such assessments of the previously identified RRI criteria with the overall aim of identifying and developing science education assessment indicators particularly related to the four RRI learning dimensions addressed: RRI values, transversal competences, and experiential and cognitive learning aspects.

To do that, we used the Scopus scientific database (https://www.scopus.com/) as the search engine due to its extensive database of peer-reviewed international journals and to ensure the rigour and comparability of the data provided. Due to the focus of the review on the operationalisation of RRI learning outcomes and process requirements in science education assessments, we defined our keywords so as to only include articles describing assessment methods on science learning and/or engagement activities.[1] Consequently, our sample is not representative of all assessment frameworks applied in science education and our analysis is not intended to be exhaustive, but rather illustrative of general trends which can be observed in this field in order to inform the proposal of RRI indicators.

A first screening provided a list of 165 scientific papers and book chapters, which was then reduced to a sample of 56 relevant ones according to a set of eligible criteria. Our selection criteria were: (i) assessment directly focused on science learning and engagement related to educational activities or projects; (ii) assessment methodology described in the paper; (iii) context and target group related to formal or informal learning and education with young people, from primary to university level; and (iv) case study articles, conceptual articles and/or articles dealing only with reviews or secondary data were excluded. Using a snowball sampling strategy (e.g. other papers cited in the reviewed articles), we then identified an additional set of 15 relevant articles, obtaining a final sample of 72 articles (68 corresponding to peer-reviewed journals and 4 to book chapters, see Appendix 1). Peer-reviewed articles covered 39 different scientific journals, among them: the *International Journal of Science Education* ($n = 11$), *Science Education* ($n = 5$) and *Computers and Education* ($n = 5$).

Data from the selected articles were collected and organised according to: (i) variables characterising the educational activity (e.g. length, number of participants, topics approached or type of participation), (ii) variables characterising the assessment methodology (e.g. assessment focus, data collection methods or analysis strategies), and (iii) aspects included in the reviewed assessment to address criteria related to the different identified RRI learning outcomes and process requirements according to our analytical framework (see both tables in Appendix 2 for details). We conducted a basic descriptive analysis to characterise the identified educational activities and assessment frameworks, as well as a conventional content analysis (Hsieh & Shannon, 2005) to identify potential indicators providing specific information of each RRI criteria. We also included an open category for ‘other criteria’ in order to allow for the inclusion of unexpected and emergent criteria when assessing RRI learning outcomes. We finally conducted an inferential analysis, and specifically the Fisher’s exact test, using the software Stata 13 (Sprent & Smeeton,

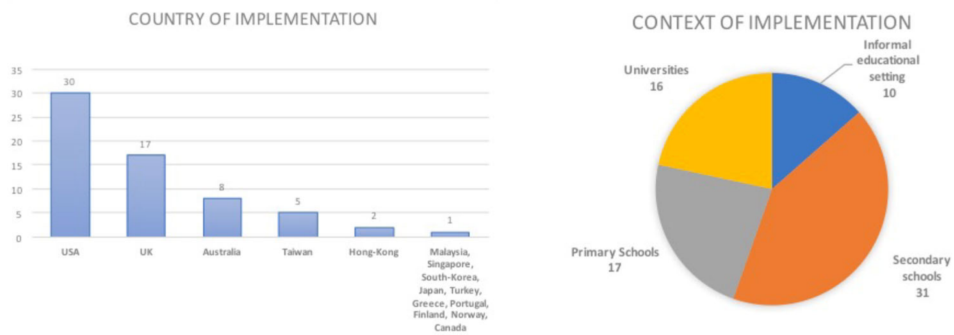

Figure 1. Broad characterisation of the science education activities included in our review ($n = 72$).

2001), to explore patterns of relation within the aspects assessed and between these aspects and the assessment methods applied.

RRI criteria in the science education assessments explored

Results of these reviewed articles allowed us first to characterise the science education activities explored (see Figure 1) and their assessment frameworks. These activities were assessed through a diversity of assessment approaches and methods (see Figure 2). In most of the cases students were the main source of data collection, whereas only a third of these activities also included teachers or educators. Assessment approaches were balanced between mixed ($n = 29$) and quantitative approaches ($n = 27$), while assessments applying only qualitative approaches were less common ($n = 15$). Similarly, quantitative analyses ($n = 59$) were more often developed than qualitative ones ($n = 43$).

Regarding data collection tools, there was a clear predominance of written questionnaires, from which 21 used only close-ended questions, 18 combined closed-ended and open-ended items and 15 used only open-ended questions of a qualitative nature. Observation (both structured and unstructured), interviews and self-reported scales were also commonly applied (see Figure 1). These results highlighted the lack of qualitative data

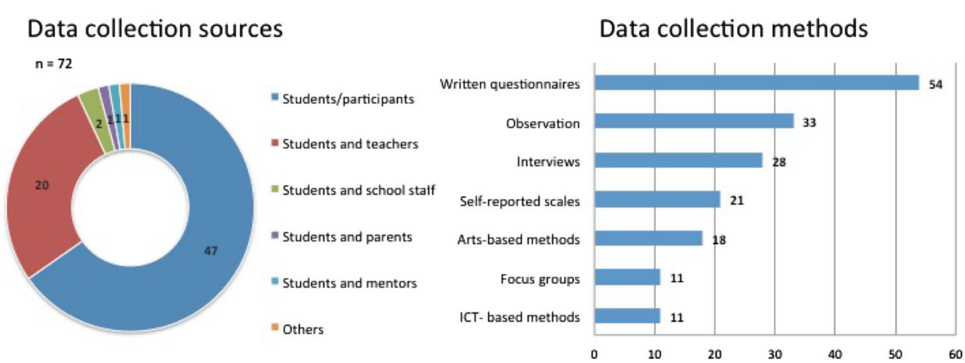

Figure 2. Data collection sources and methods in the assessments reviewed ($n = 72$).

in part of the assessments and/or, eventually, of an in-depth exploration of these data, as well as the use of partial assessments leading to incomplete evidence – e.g. assessments that did not cover the whole activity, did not include relevant involved actors as data sources, or used only cross-sectional data.

Regarding how these activities included the different RRI criteria, results showed that, although the focus of the assessments was diverse in terms of targeted learning outcomes and process requirements, students' cognitive aspects were, by far, the most assessed (Figure 3). This basic cognitive dimension was addressed mostly in terms of the 'Acquisition of conceptual knowledge', which encompassed the assessment of students' assimilation, acquisition and refinement of explicit scientific facts and concepts and was the most common criterion in the assessments reviewed. Furthermore, 'Reflective thinking' was also commonly included in the reviewed assessments as a criterion involving cognitive skills, and also related to transversal competences (see below). Similarly, three of the most cited criteria related to RRI values were related to cognitive aspects: 'Cognitive engagement' or the attention required during a task or process, 'Questioning and reframing' implying high-order thinking skills and 'Systems thinking' or the ability to connect ideas and topics, identify patterns and relationships and think from multiple perspectives. Besides these criteria mainly related to cognitive aspects, we found a group of less frequent, but still considered, criteria for RRI values. This group included: 'Fostering dialogue among participants', addressed in the assessments as students' engagement in discussion and talk, questioning within groups and development of shared understandings; 'Connecting topics with experience', referred to the ability to contextualise scientific phenomena, link experiences to concepts, and apply knowledge; and 'Emotional engagement', included as students' appreciation of science, intrinsic motivation and experiential value.

Interestingly, gender and ethical issues – core aspects of RRI – stand out for their absence in most of the assessments reviewed. Criteria related to ethical aspects were especially absent in regards to: 'Connecting scientific topics with values'; the 'Social relevance of topics addressed', approached by assessing the contextualisation of scientific topics and research within social challenges; and 'Participants acceptance of process/outcomes', mostly approached by assessing participants' creation and ownership of outcomes. Similarly, only five assessments within the whole sample critically addressed gender aspects, beyond the usual identification of participant numbers according to gender. This critical approach to gender was assessed mostly by documenting gender differences in performance and/or outputs and by looking at different affective responses according to gender.

The experiential dimension of learning was commonly assessed in terms of aspects related to students' general values, perceptions and attitudes towards science. Indeed, 'Attitudes towards science and/or the scientific issues approached' and 'Perceptions towards science and/or the scientific issues approached' were two of the most commonly included criteria in the assessments. These criteria were approached mostly by assessing participants' interest, sympathy and motivation towards science and scientific careers and their perceptions about the specific scientific topics approached and the learning activity. In contrast, we rarely found criteria related to students' emotions and feelings associated with the activity (see Figure 2). Only 'Enjoyment' escaped this trend, approached through the assessment of enthusiasm or excitement when doing science-related activities, having fun or enjoying the learning experience. 'Emotional awareness

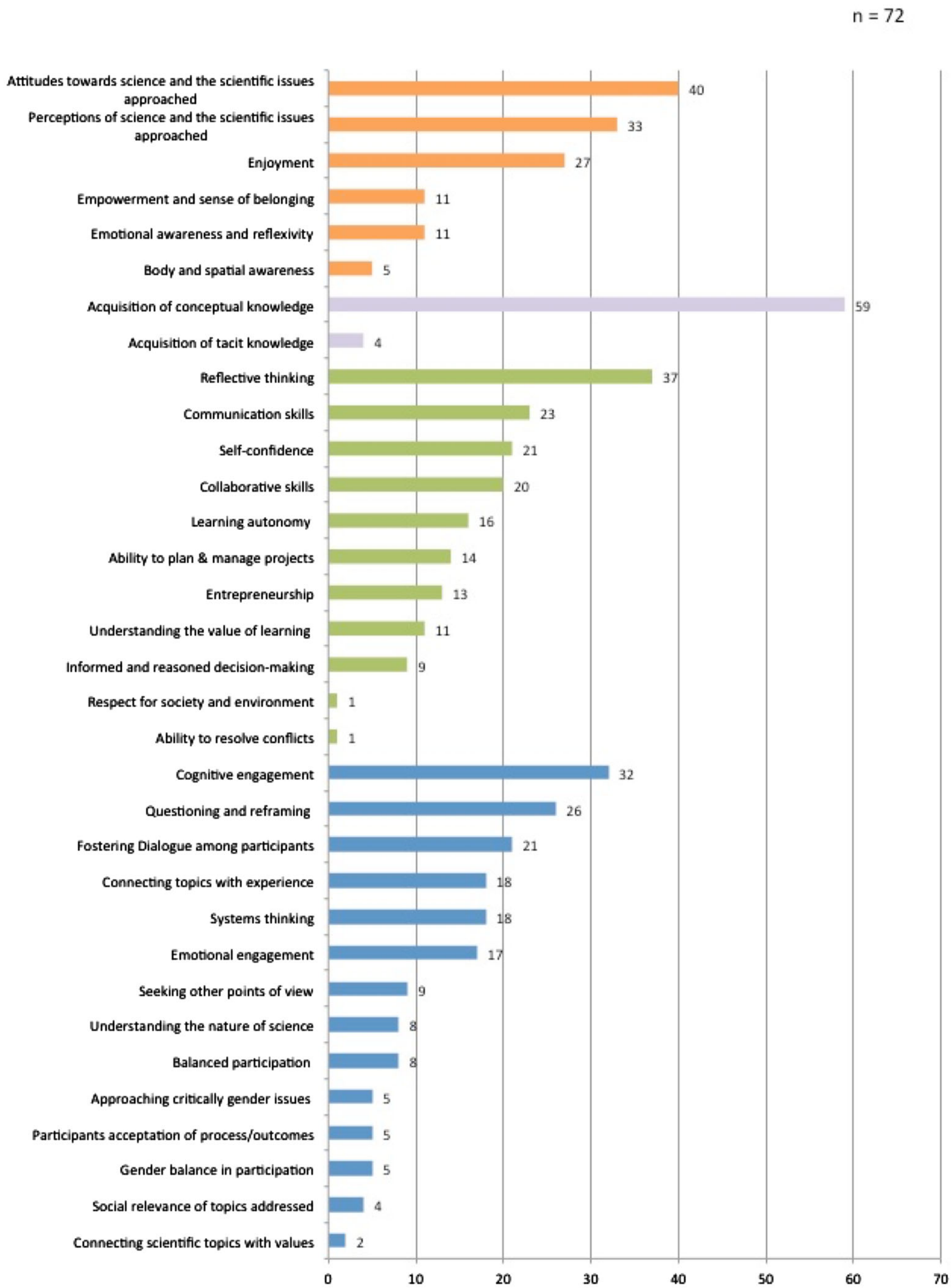

Figure 3. Assessment criteria and number of mentions in the reviewed studies (*n* = 72). Colours indicate the dimension of the criteria: orange – experiential aspects of learning; purple – cognitive aspects of learning; green – transversal competences; and blue – RRI values.

and reflexivity' (addressed as feelings and affective expressions related to the activities, and as affective processing) and 'Empowerment and sense of belonging' (approached as sense of agency, self-confidence, group identity, feeling of trust amongst peers or social relatedness) were the second most assessed criteria in this group, but to a lesser extent.

The assessment of the dimension of transversal competences was unbalanced in terms of criteria addressed. Although criteria related to this dimension were included in more than a half of studies, this was mostly due to the assessment of 'Reflective thinking' aspects, such as students' capacity to develop explanations, interpret facts, ask relevant questions or be self-reflexive. 'Communication skills', 'Collaboration skills' and 'Self-confidence' were the next most cited criteria, but they were included to a much lesser extent in the assessments. These skills were approached, among others, by assessing students' expressivity, oral communication and exchange of ideas and knowledge, peer-support, team-work skills and confidence in speaking-up and/or asking questions. Other transversal competences were punctually included in the assessments, such as 'Ability to resolve conflicts', 'Respect for society and environment', 'Informed and reasoned decision-making' and 'Understanding the value of learning'.

Finally, results from the inferential analysis showed few significant associations among and between variables assessed and methods used, but provided complementary insights for our understanding of the review. As expected, perceptions and attitudes towards science were commonly and significantly assessed together, mostly through mixed methods approaches. In contrast, the assessment of basic cognitive aspects (i.e. assimilation of concepts and facts) was not significantly related with the assessment of more complex cognitive aspects, meaning that those studies assessing basic and tacit cognitive aspects did not necessarily evaluate higher-order thinking skills such as cognitive engagement, systems thinking, questioning and reframing and reflective thinking. Regarding the methodological approaches used, the use of quantitative methods was significantly and positively associated with the measurement of the acquisition of conceptual knowledge (basic cognitive aspect). Conversely, the use of qualitative methods was significantly related to the assessment of students' development of social skills, sense of initiative, ethical aspects and reflexive thinking.

Proposal of RRI-related assessment indicators in science education

As a result of the content analysis of the review, we identify a set of 86 assessment indicators corresponding to the 32 assessment criteria of our analytical framework based on the RRI learning dimensions (Table 2). Identified indicators consist of observable and measurable characteristics of the learning process and/or resulting learning outcomes related to the assessment criteria, focusing on the development of the educational activity (including teachers' performance), students' performance and interactions between teacher and students. In doing so, the indicators incorporate and expand the RRI values, transversal competences and experiential and cognitive aspects of science learning and engagement previously identified. Process requirements are reflected in at least 21 indicators, while 65 indicators assess only learning outcomes. Our interest in indicators related to RRI values resulted in 41 indicators identified for this dimension.[2] Among these, we have emphasised indicators related to cognitive engagement, gender and balanced participation. We have also identified 33 indicators for the two dimensions of

Table 2. Indicators proposed for the four learning dimensions identified.

Indicators proposed for the dimension basic cognitive aspects of learning		
LO and/or PR	**Criteria**	**Indicators**
Acquisition of knowledge	Acquisition of conceptual knowledge	1. Student's acquisition of basic knowledge about scientific topic(s) addressed in the activity
	Acquisition of tacit knowledge	2. Student's acquisition of tacit knowledge (procedural information) from experiencing the activity
		Also includes indicators 32, 39, and 69
Indicators proposed for the dimension experiential aspects of learning		
LO and/or PR	**Criteria**	**Indicators**
Feelings and emotions	Enjoyment	3. Student's interest in science and learning science
		4. Excitement caused by science and learning science
		5. Student's amusement during the activity
	Emotional awareness and reflexivity	6. Student's expression and/or embodiment of emotions related to the topic of the activity
		7. Student's ability to reflect upon and through her/his emotional responses and make consistent behavioural choices in the activity.
		Also includes indicators 5, 60
	Body and spatial awareness	8. Student's use of the body to convey meanings and kinaesthetic understandings
		9. Student's awareness of the influence of the physical space in their learning and engagement in the activity
		Also includes indicator 61
	Empowerment and sense of belonging	10. Student's sense of belonging to the community when doing the scientific activity
		11. Appropriate design of the activity to address students' resources and competences
		12. Student feeling recognized by other participants beyond their classmates
		Also includes indicators 18, 41, 44, 45
Attitudes and perceptions	Perceptions of science and the scientific issues approached	13. Student's perceptions of the social value of science
		14. Student's perceptions of scientists, scientific careers and/or jobs
		15. Student's perceptions of the specific topics approached in the activity
		16. Student's perceptions of the way science is taught at schools
		17. Student's perceptions of the pedagogic approach and methods used in the activity
		18. Student's perceptions of the group in the activity, including sense of belonging
		Also includes indicators *3, 5, 22, 23,24, 80, 81*
	Attitudes towards science and the scientific issues approached	19. Student's curiosity and interest towards science
		20. Student's identification with scientific skills and attributes
		21. Student's interest in scientific careers and/or jobs
		22. Student's attitudes towards the topics approached in the activity
		23. Student's attitudes towards the pedagogic approach and methods used in the activity
		Also includes indicators 3, 4, 5, 13, 24, 25, 38, 59, 67
Indicators proposed for the dimension transversal competences		
LO and/or PR	**Criteria**	**Indicators**
Learning to learn	Understanding the value of learning	24. Student's awareness of the professional value of learning science
		25. Student's satisfaction to be able to learn science
		26. Student's awareness of the value of experiencing science in a given learning environment

Table 2. Continued.

	Learning autonomy	27. Student's ability to organise their own learning by setting own goals in the process 28. Student's ability to use equipment, technology and/or tools to perform the activity 29. Student's ability to persist in a scientific task despite failure and difficulty 30. Student's ability to autonomously search for relevant and rigorous information *Also includes indicators 65, 66, 68*
	Reflective thinking	31. Student's reflection on her/his own learning during the activity 32. Student's ability to recognize relevant information and use it effectively in the activity 33. Student's assessment and reflection about peers' performance in the activity *Also includes indicators 39, 64, 70, 71*
Social and Civic competences	Communication skills	34. Student's ability to elaborate and share ideas verbally and written during the activity 35. Student's ability to organise and make meaning from visual information in the activity *Also includes indicator 61*
	Collaborative skills	36. Student's willingness to ask for help and/or to help others to perform the activity 37. Student's respect towards others' ideas when doing the activity *Also includes indicators 33, 40, 50*
	Respect for society and environment	38. Student's willingness to assume a responsible position to socially relevant issues addressed in the activity
	Informed and reasoned decision-making	39. Student's ability to contrast different evidence to provide explanations *Also includes indicators, 38, 64, 66*
	Ability to resolve conflicts	40. Student's ability to contribute to the activity through managing difficulties within the group
Sense of initiative	Entrepreneurship	41. Student's belief in her/his own ability to perform a scientific activity 42. Student's leadership and/or responsibility in the performance of a group activity 43. Student's performance self-assessment during the activity and of its outcomes *Also includes indicator 27*
	Self-confidence and esteem	44. Student's belief in her/his own ability to do well in a scientific domain 45. Student's belief in her/his own verbal ability to discuss about science *Also includes indicators 41, 12*
	Ability to plan and manage projects	46. Student's ability to plan and/or perform a scientific task and/or project *Also includes indicators 41, 43*
Indicators proposed for the dimension RRI values		
LO and/or PR	**Criteria**	**Indicators**
Inclusiveness of all participants	Balanced participation	47. Combination of learning pedagogies and resources in the activity to reach all students in the activity 48. Specific support to students with special needs during the activity 49. Inclusion of other participants in the activity (beyond students) and their expertise 50. Student's sharing of tasks and roles in processes and outputs during the activity *Also includes indicators 51, 53, 55*
	Fostering dialogue among participants	51. Type of dialectic interactions among students in collective creation and group work, if any 52. Student's use of interactive ICT tools in the activity 53. Characteristics of dialogue between students and teachers in the activity *Also includes indicator 49*

(*Continued*)

Table 2. Continued.

Gender equality	Gender balance in participation	54. Student's engagement in science in and out school by gender 55. Number of students in the activity by gender 56. Type of tasks and roles assumed by students in the activity
	Approaching critically gender issues	57. Student's affective responses to the activity by gender 58. Student's performance in the activity by gender *Also includes indicators 47, 54, 56*
Engagement	Emotional engagement	59. Student's willingness to get involved and participate in the activity 60. Student's feelings when experiencing the activity, if any 61. Student's ability to use the body to express and communicate scientific ideas and concepts 62. Student's involvement of emotions in the process of meaning making 63. Student's further interaction and initiatives related to the activity once it is over *Also includes indicator 83*
	Cognitive engagement	64. Student's degree of involvement in reasoning and argumentation in the activity 65. Student's ability to develop ideas and engage in higher-order thinking 66. Student's ability to ask questions, discuss and develop conclusions and/or solutions 67. Time spent by the student in doing the task during the activity 68. Student's willingness to continue working in the activity out of class *Also includes indicators 29, 51, 59, 63, 69, 83*
Critical and creative thinking	Questioning and reframing	69. Student's reframing and/or comprehension of scientific concepts based on rationality 70. Student's ability to formulate and test hypotheses and/or research questions *Also includes indicators 65, 66, 71*
	Systems thinking	71. Student's ability to relate ideas from multiple topics in multiple contexts 72. Student's awareness of issues of scale when approaching scientific topics 73. Student's ability to identify relations and interactions between different elements of a system 74. Use of learning techniques to represent and/or discuss about the whole system in the activity *Also includes indicator 79*
	Connecting topics with experience	75. Contextualization of scientific topics within societal challenges in the activity 76. Use of students' previous experiences and knowledge as a basis for learning in the activity 77. Facilitation of students' learning through direct, active involvement during the activity 78. Student's ability to apply science concepts to different tasks and/or contexts
	Seeking other points of view	79. Student's ability to consider different perspectives and points of view
Ethics integration	Understanding of the nature of science (NOS)	80. Student's awareness of science contradictions, uncertainty, failure and/or risk 81. Student's awareness of power relations in science *Also includes indicator 85*
	Social relevance of topics addressed	82. Give students the possibility to make learning choices in the scientific activity *Also includes indicator 75*
	Participants acceptance of process/outcomes	83. Student's creation of own outcomes in the activity *Also includes indicator 82*
	Connecting scientific topics with values	84. Inclusion of scientists' personal stories in the activity 85. Inclusion of contrasting perspectives regarding the role of science with and for society 86. Student's reflection about ethical behaviour in research

Note: LO: learning outcome; PR: process requirement.

transversal competences and experiential aspects of learning. Among the indicators of transversal competences, those referring to learning autonomy and reflective thinking have been more developed. Within the experiential dimension, the high proportion of indicators identified for perceptions and attitudes towards science reflects the emphasis given in the literature to these aspects. Finally, and due to our focus on RRI, which is less concerned with basic cognitive aspects, we have compiled only five indicators of this learning dimension, two of them related to the acquisition of conceptual and tacit knowledge, and the other three overlapping with other cognitive skills (i.e. recognition of relevant information, reframing of scientific concepts, reasoning).

A role for RRI indicators within science education assessments?

A gap in science education frameworks

The results of this review of studies show diverse assessment foci and methods that suggest different levels of assessment of RRI learning outcomes in terms of analytical depth. First, we found a basic level of analysis addressing basic cognitive and experiential aspects through the measurement of knowledge gains and changes in attitudes towards and perceptions about the scientific topics approached. This level is often covered by the studies reviewed, mostly through quantitative data collection tools, such as close-ended questionnaires and Likert scales (e.g. Sadler, Romine, Menon, Ferdig, & Annetta, 2015; Savoy, Proctor, & Salvendy, 2009; Whitehouse et al., 2014). A second level expands the assessment of RRI learning outcomes to the acquisition of transversal skills and competences. This was also approached through performance-based assessments, mainly focused on students' inquiry and communication skills (e.g. Rooney-Varga, Brisk, Adams, Shuldman, & Rath, 2014; So et al., 2010). A third level of analysis in the assessments further addresses the metacognitive, normative and emotional dimensions of learning, involving a leap forward to include critical thinking, reflexivity, values and emotions. Such an assessment focus was rarely found in our review (e.g. Fitzgerald & Gunstone, 2013).

The predominance of assessment approaches within the first identified level suggests a gap between the holistic and complex understanding of science education under the RRI approach and the focus of the methodological frameworks reviewed, which might be illustrative of a general trend in the assessment of science education activities.[3] While indicators addressing the cognitive aspects of learning are widely implemented, indicators related to specific RRI values, transversal competences and emotional aspects of learning are missing in most of the assessments reviewed or are approached in rather narrow ways (e.g. only through quantitative scales). Not surprisingly, the less frequently included criteria often correspond with the less tangible and more subjective dimensions of learning (e.g. emotional reflexivity and awareness, sense of belonging, body awareness, empowerment) or with skills that require observation and interpretation of performance (e.g. ability to resolve conflicts, informed and reasoned decision-making, entrepreneurship). A partial explanation might be found in the data collection methods and analysis strategies applied, as well as the time-frameworks required to approach these aspects. Our inferential analysis points in this direction, showing significant correlations between these criteria and the use of qualitative methods. Indeed, educational research has shown the difficulty of approaching complex learning variables, such as values and affective responses, only through quantitative methods and analysis (Klassen, 2006; Osborne, Simon, & Collins, 2003; Ruiz-Primo, 2011). For instance, the extended use of attitude scales in isolation may help identifying attitudinal trends, but be of little contribution to their understanding (Osborne et al., 2003). The implementation of more sophisticated assessments might be hindered, however, by other contextual factors, such as science curriculum pressures leading to standardised, high-stakes assessments, and teachers' implementation capacity and resources – for instance, limitations to provide classroom opportunities for using transversal skills, which demand more time and resources from teachers (Harlen, 1999; Klassen, 2006; Towndrow, 2008). Such contextual factors also influence the nature of the educational activities developed (i.e. goals, processes fostered, time frameworks), which are, in turn, crucial in determining assessment development possibilities (Harlen, 1999). Better alignment between curriculum and emergent pedagogies therefore seems an essential contribution to assessment developments aimed at approaching learning complexity (Towndrow, 2008).

Furthermore it is noteworthy that within this gap in the reviewed studies, some RRI process requirements that could be, in principle, easier to track and monitor, are amongst the most neglected criteria. This is the case of gender equality and ethics integration, which are, by far, the most absent RRI-related criteria in the assessments reviewed. In this regard, except for those educational activities exploring innovative methodologies (e.g. ICT or arts-based science education), most of the reviewed assessments focus on learning outcomes, rather than process dimensions. However, procedural aspects, including teaching strategies and learning activities, shape the learning environment and should be carefully monitored, as they can strongly influence students' learning experiences and attitudes towards science (Osborne et al., 2003).

Addressing the gap: the role of RRI indicators

Designing multilevel RRI assessments is, thus, a challenging but necessary task in the approach to complex learning experiences within science education. The RRI assessment criteria and indicators proposed in this article provide an open assessment framework contributing to this task. More specifically, we identify at least three potential complementary ways in which the suggested indicators can approach such complexity and reduce the assessment gap identified in our review of studies: reflecting the multidimensionality of learning, integrating reflexivity within the learning process and broadening data sources and time frameworks.

Multidimensionality of learning

Being able to capture the complexity of learning and the learning experience has been a constant concern in science education assessments since the constructivist turn (Klassen, 2006). The application of RRI lenses in science education assessments provides an opportunity to approach such complexity, by comprising a broad range of learning outcomes and process requirements – ranging from cognitive and experiential aspects of learning, to skills and values. On the one hand, RRI approach to science both as a content and as a process emphasises the exploration and development of competences and skills related to scientific thinking, and the focus on students' understanding of the nature of science. Understanding the nature of science, including the normative aspects, power relations and tensions that intervene and coexist in the construction and sharing of scientific knowledge is crucial to foster critical scientific literacy, active citizenship and engagement in science (Klosterman & Sadler, 2010; Priest, 2013). The identified assessment indicators encompass such an understanding of science, addressing a variety of values, skills and ethical aspects related to scientific practice. On the other hand, the emphasis of RRI on process requirements allows for the monitoring of the educational process and design, and the extent to which it provides the opportunities and resources for different learning experiences to happen. Inclusivity is enhanced as a crucial requirement in our assessment framework, especially in terms of gender equality and students' appropriation of the learning process. Gender issues are specifically relevant in scientific practice and science education since girls' and boys' attitudes and perceptions are differently influenced by different reference models and negative stereotypes (Osborne et al., 2003). Despite the recognition of the need to address gender issues in science education and the efforts in this direction (Brickhouse, 2001; EU, 2015; Kahle, Parker, Rennie, & Riley, 1993), the general denial of gender equality in the reviewed assessments calls for a further integration of these aspects in assessment developments in the field of science education. Our assessment framework contributes to such a methodological development by providing at least eight indicators directly related to gender equality.

Assessment for and assessment as learning

Through the emphasis on reflexivity and other RRI process dimensions, the proposed indicators are expected to enrich the learning experience. Indeed, we conceive our assessment framework as a tool facilitating both assessment *for* and assessment *as* learning experiences (Corrigan, Buntting, Jones, & Gunstone, 2013). The former implies that the assessment is carefully integrated into the science educational activities, contributing to students' learning as it happens by involving reflection and self-reflexivity. Paying attention to integrating assessment indicators such as 'Understanding of the value of learning', 'Learning autonomy', 'Reflective thinking', 'Emotional awareness' and 'Body and spatial awareness' can contribute to actively engage students in the learning process and empower them, by fostering responsibility for their learning and by developing learning skills. Furthermore, the second assessment approach implies that monitoring and evaluation are also understood as self-reflexive, iterative research processes for teachers and educators aiming to contribute to the improvement of the educational activities proposed. Indicators addressing inclusiveness, gender and ethical issues are specifically relevant to the purpose of such assessment.

Broadening time frameworks and sources of data collection

Using the suggested indicators to capture changes in participants along the educational process requires a reconsideration of time frameworks and data sources in the design of the assessment. Indicators are expected to be applied before, during or after the educational activity, depending on the educational context and purpose of assessment. This can be challenging in certain cases (e.g. one shot activities), but should be taken into account while assessing longer interventions, if the richness of the learning experience is to be addressed. In addition, although the focus of our framework still remains on students, the indicators on process requirements extend the assessment to the performance of the educator/teacher and her/his interaction with the students (e.g. 'Giving students the possibility to make learning choices in the scientific activity', or 'Characteristics of dialogue between students and teachers in the activity'). Placing attention on such interactions is not only a way of capturing a relevant aspect of the learning experience, but also of triangulating data sources while focusing both on students' and teachers' performance and on the activity design (Golafshani, 2003).

Conclusion: moving forward

This research has aimed to contribute to the operationalisation of RRI within science education assessments through a proposal of an analytical framework informed conceptually by the RRI paradigm and empirically by different developments in science education assessments. While basic cognitive and experiential aspects, such as the assimilation of conceptual knowledge and perceptions and attitudes towards science, are commonly included in such assessments, other complex cognitive and emotional learning aspects are frequently neglected.

Through the identification of 86 RRI assessment indicators specifically related to science learning and engagement among young people, this research provides an open and evolving framework that has the potential to move forward the state of the art in such assessment developments and to address such neglected learning outcomes. Such a contribution is twofold. On the one hand, looking at science education assessments under the lenses of the RRI approach provides an opportunity to encompass learning multidimensionality, potentially contributing to bridging the gap between theoretical conceptualisations of learning and their operationalisation in practice. This is intended, mainly, by embracing different learning dimensions and approaches – including ethical aspects, integrating the assessment into the learning experience and broadening data collection time frameworks and sources. On the other hand, by focusing on science education, the paper addresses a key element already highlighted in previous reports on RRI (Strand et al., 2015): the necessary identification of assessment indicators tailored to each policy agenda and RRI context. In doing so, this research contributes to operationalising the concept of RRI in education, a necessary step to strengthen its implementation and value.

Such a contribution needs to be understood in the context of this emerging field. Despite their potential, the proposed indicators do not represent an exhaustive framework, nor a checklist to be followed. On the contrary, assessment criteria should be open to further developments and contextual reinterpretations if the richness and specificities of the different learning contexts and experiences are to be addressed. A realistic assessment implementation will probably require prioritising certain criteria, since it seems unlikely that all indicators can be measured at the same time.

Finally, this proposal is supported by an expert-based literature review that can be expanded through further reviews. Moreover, under the lenses of the RRI approach, the legitimacy and impact of the assessment requires, ideally, the inclusion of all relevant stakeholders in the design (Strand et al., 2015). The framework should thus be further developed and reinforced with the views of other relevant stakeholders in science education, such as participant students and teachers. Although not included here, our literature review was complemented by a series of exploratory workshops with secondary school students in selected schools in Spain, UK and France to include their views on the assessment through the development of participatory indicators (see Heras et al., 2016). Further conceptual and empirical work is necessary for testing and improving the proposed science education assessment framework. We hope that this research effort can guide such methodological developments and contribute to the meaningful implementation of RRI in the context of science learning and engagement.

Notes

1. Keywords applied: (TITLE-ABS-KEY ('science Learning' OR 'science engagement') AND ALL (assessment OR evaluation) AND ALL (framework OR approach OR perspective OR method)). We limited the search to articles and book chapters as document type, but included all subject areas and all years to present in the data range.
2. Note that some indicators are relevant for several dimensions. Therefore, while the total number of indicators is 86, the sum of indicators across all dimensions is higher than this number.
3. Since our sample is focused on specific practical developments (case studies included in the sample), this gap is suggested between theory and practice and not in conceptual developments of science education assessments, which are not the focus of this article.

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Appendices

Appendix 1. List of articles and book chapters included in the literature review

		Bibliographic information			
	1st Author	Title	Journal Name	Year	Paper ID
1	Akpinar, Yavuz	Teachers' collaborative task authoring to help students learn a science unit	*Educational Technology and Society*	2006	36
2	Akpinar, Yavuz; Bal, Volkan	student tools supported by collaboratively authored tasks: The case of work learning unit	*Journal of Interactive Learning Research*	2006	25
3	Anastopoulou, Stamatina	An evaluation of multimodal interactions with technology while learning science concepts	*British Journal of Educational Technology*	2011	46
4	Annetta, Leonard A.	Investigating the impact of video games on high school students' engagement and learning about genetics	*Computers & Education*	2009	54
5	Aubusson, Peter	What happens when students do simulation-role-play in science?	*Research in Science Education*	1997	60
6	Aubusson, Peter	Role play as analogical modelling in science	*Metaphor and analogy in science education* (Book)	2006	61
7	Bailey, S	Establishing basic ecological understanding in younger pupils: A pilot evaluation of a strategy based on drama/role play	*International Journal of Science Education*	1998	64
8	BATHGATE, Megan	Children's motivation toward science across contexts, manner of interaction, and topic	*Science Education*	2013	3
9	Bathgate, Megan	The learning benefits of being willing and able to engage in scientific argumentation	*International Journal of Science Education*	2015	7
10	Boddy, Naomi	A trial of the Five Es: A referent model for constructivist teaching and learning	*Research in Science Education*	2003	38
11	Braund, Martin	Electric drama to improve understanding in science	*School Science Review*	1999	66
12	Brown, Bryan A; Kloser, Matt	Conceptual continuity and the science of baseball: using informal science literacy to promote students' science learning	*Cultural Studies of Science Education*	2009	26
13	Chang, Chun-Yen	Preferred – Actual learning environment 'spaces' and earth science outcomes in Taiwan	*Science Education*	2006	35
14	Cheng, Vivian M.Y.	Infusing creativity into Eastern classrooms: Evaluations from student perspectives	*Thinking Skills and Creativity*	2011	41
15	Clark, Douglas B	Assessing dialogic argumentation in online environments to relate structure, grounds, and conceptual quality	*InterScience*	2007	29
16	Clark, Douglas B.	Exploring Newtonian mechanics in a conceptually-integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United States	*Computers and Education*	2011	20
17	Dorion, Kirk	A learner's tactic: How secondary students' anthropomorphic language may support learning of abstract science concepts	*Electronic Journal of Science Education*	2011	50

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		Bibliographic information			
	1st Author	Title	Journal Name	Year	Paper ID
18	Dorion, Kirk	Science through Drama: A multiple case exploration of the characteristics of drama activities used in secondary science lessons	*International Journal of Science Education*	2009	53
19	Engle, Randi A.	Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom	*The Journal of the Learning Sciences*	2006	59
20	Etkina, Eugenia	Design and reflection help students develop scientific abilities: Learning in introductory physics laboratories	*Journal of Learning Sciences*	2010	34
21	Fitzgerald, Angela	Embedding assessment within primary school science: A case study	*Valuing Assessment in Science Education: Pedagogy, Curriculum, Policy* (Book)	2013	15
22	Gobert, Janice D.	Using educational data mining to assess students' skills at designing and conducting experiments within a complex systems micro-world	*Thinking Skills and Creativity*	2015	10
23	Gold, Anne	Lens on climate change: Making climate meaningful through student-produced videos	*Journal of Geography*	2015	8
24	Hampden-Thompson, Gillian	Science teaching and learning activities and students' engagement in science	*International Journal of Science Education*	2013	18
25	Harris, Christopher	Impact of project-based curriculum materials on student learning in science: Results of a randomized controlled trial	*Journal of Research in Science Teaching*	2015	6
26	Harrower, Mark	Developing a geographic visualization tool to support earth science learning	*Cartography and Geographic Information Science*	2000	43
27	So, Hyo-Jeong	Designing collaborative knowledge building environments accessible to all learners: Impacts and design challenges	*Computers and Education*	2008	27
28	Jarman, Ruth	Science learning through Scouting: An understudied context for informal science education	*International Journal of Science Education*	2005	37
29	Jarvis, Claire	Podcasts in support of experiential field learning	*Journal of Geography in Higher Education*	2010	57
30	Jensen, Eric	Evaluating children's conservation biology learning at the zoo	*Conservation Biology*	2014	14
31	Kazmer, Michele M.	Produsage in a/synchronous learner-led e-learning	*New Review of Hypermedia and Multimedia*	2011	42
32	Kearney, Matthew	Students in the director's seat: Teaching and learning with student-generated video	*World Conference on Educational Multimedia, Hypermedia and Telecommunications*	2005	47
33	Klosterman, Michelle L.	Multi-level assessment of scientific content knowledge gains associated with socioscientific issues-based instruction	*International Journal of Science Education*	2010	55
34	Kozaitis, Kathryn A.	Partners in reform: 'What's culture got to do with it?'	*Urban Anthropology*	1997	40
35	Lamb, Richard	Cognitive diagnostic like approaches using neural-network analysis of serious educational videogames	*Computers & Education*	2014	11

(*Continued*)

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		Bibliographic information			
	1st Author	Title	Journal Name	Year	Paper ID
36	Lau, Kwok-chi	Impacts of a STSE high school biology course on the scientific literacy of Hong Kong students	*Asia-Pacific Forum on Science Learning and Teaching*	2013	19
37	Loukomies, Anni	Promoting students' interest and motivation towards science learning: The role of personal needs and motivation orientations	*Research in Science Education*	2013	17
38	Lee, Silvia Wen-Yu	Impact of biology laboratory courses on students' science performance and views about laboratory courses in general: Innovative measurements and analyses	*Journal of Biological Education*	2012	70
39	Clary, Renee M.	Scientific caricatures in the earth science classroom: An alternative assessment for meaningful science learning	*Science and Education*	2008	28
40	Marques, Isabel	Bioinformatics projects supporting life-sciences learning in high schools.	*PLoS Computational Biology*	2014	12
41	McGregor, Debra	Chronicling innovative learning in primary classrooms: Conceptualizing a theatrical pedagogy to successfully engage young children learning science	*Pedagogies: An International Journal*	2014	13
42	McGregor, Debra	Dramatising Science Learning: Findings from a pilot study to re-invigorate elementary science pedagogy for five- to seven-year olds	*International Journal of Science Education*	2012	51
43	Metcalfe, Robert	Teaching science through drama: An empirical investigation	*Research in Science & Technology Education*	1984	62
44	Mylopoulos, Maria	Preparing medical students for future learning using basic science instruction.	*Medical Education*	2014	68
45	Nyachwaya, James M.	The development of an open-ended drawing tool: an alternative diagnostic tool for assessing students' understanding of the particulate nature of matter	*Chemistry Education Research and Practice*	2011	44
46	Palmer, David H.	Using dramatizations to present science concepts. Activating students' knowledge and interest in science	*Journal of College Science Teaching*	2000	67
47	Pugh, Kevin	Motivation, learning, and transformative experience: A study of deep engagement in science	*Science Education*	2009	1
48	Prince, Katinka J A H	Does problem-based learning lead to deficiencies in basic science knowledge? An empirical case on anatomy	*Medical Education*	2003	71
49	Rivet, Ann E.	Contextualising instruction: Leveraging students' prior knowledge and experiences to foster understanding of middle school science	*Journal of Research in Science Teaching*	2008	30
50	Rodrigues, Susan	Factors that influence pupil engagement with science simulations: the role of distraction, vividness, logic, instruction and prior knowledge	*Chemistry Education and Research Practice*	2007	33

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		Bibliographic information			
	1st Author	Title	Journal Name	Year	Paper ID
51	Rondon, Silmara	Computer game-based and traditional learning method: a comparison regarding students' knowledge retention.	*BMC Medical Education*	2013	69
52	Rooney-Varga, Juliette N.	Student media production to meet challenges in climate change science education	*Journal of Geoscience Education*	2014	56
53	Rowe, Elisabeth	Serious games analytics to measure implicit science learning	*Serious Games Analytics* (Book)	2015	4
54	Sadler, T.D.	Learning biology through innovative curricula: A comparison of game- and nongame-based approaches	*Science Education*	2015	5
55	San Miguel, Sandra	Fat dogs and coughing horses: K-12 programming for veterinary workforce development	*Journal of Veterinary Medical Education*	2013	21
56	Savoy, April	Information retention from PowerPoint and traditional lectures	*Computers and Education*	2009	58
57	Simon, Shirley	Puppets promoting engagement and talk in science	*International Journal of Science Education*	2008	63
58	Stevens, Shawn	Learning progressions as a guide for developing meaningful science learning: A new framework for old ideas	*Educación Química*	2013	16
59	Stevenson, John	The long-term impact of interactive exhibits	*International Journal of Science Education*	1991	49
60	Taagepera, Mare	Mapping students' thinking patterns by the use of the knowledge space theory	*International Journal of Science Education*	1997	39
61	Takayesu, James K.	How do clinical clerkship students experience simulator-based teaching? A qualitative analysis	*Simulation in Healthcare*	2006	45
62	Tveita, Johaness	Can untraditional learning methods used in physics help girls to be more interested and achieve more in this subject?	*Research in Science Education in Europe*	1999	65
63	Varelas, Maria	Drama activities as ideational resources for primary-grade children in urban science classrooms	*Journal of Research in Science Teaching*	2010	52
64	Waller, Bridget M.	Evidence of public engagement with science: Visitor learning at a zoo-housed primate research centre	*PLoS One*	2012	48
65	Wang, Chien-hsing	Collaborative action research on technology integration for science learning	*Journal of Science Education and Technology*	2012	22
66	Whitehouse, Jamie	Evaluation of public engagement activities to promote science in a zoo environment.	*PLoS One*	2014	9
67	Williams, Michelle	Exploring middle school students' conceptions of the relationship between genetic inheritance and cell division	*Science Education*	2012	23
68	Woods-McConney, Amanda	Science engagement and literacy: A retrospective analysis for students in Canada and Australia	*Research in Science Education*	2014	2
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(*Continued*)

Continued.

		Bibliographic information			
	1st Author	Title	Journal Name	Year	Paper ID
70	Wui, Lee Sheh	An evaluation of a Nutrition WebQuest: The Malaysian experience	*Eurasia Journal of Mathematics, Science and Technology Education*	2008	32
71	Yoon, Sae Yeol	Korean students' perceptions of scientific practices and understanding of nature of science	*International Journal of Science Education*	2014	24
72	Yoshioka, Toshimasa	Format of cases affects learning outcomes in first year medical students	*Education for Health*	2003	72

Appendix 2. Data collection matrix

Table A1. Categories and subcategories to conduct data collection on educational activities and assessment frameworks.

Categories	Subcategories
Basic information	Publication Type; Country of implementation; Objective of the paper
	Learning approach
	Context of application; Level of education; Socio-economic status
Educational experience	Topic/s addressed
	Duration; Number of participants; Specific target group
	Participatory approach; Type of participation; Manner of interaction
Assessment framework	Focus of the assessment
	Disciplines applied/disciplinary background
	Data collection source
Assessment approach	Type of assessment approach (mix, quantitative, qualitative)
	Participatory approach
Collection methods	Self-reported scales
	Close-ended surveys
	Open-ended surveys
	Interviews
	Observation
	Focus groups
	Mural evaluation
	Arts-based methods
	Others/Key details [Specify, for instance if there's pretest]
	Takes into account unexpected outcomes?
	How?
	Appendix with collection tools
Analysis strategies	Statistical analysis
	Type of statistical analysis
	Qualitative analysis
	Type of qualitative analysis

Table A2. Categories and subcategories to conduct data collection on assessment criteria and indicators.

Categories	Subcategories	
Related to	Process requirements and learning outcomes	Assessment criteria
Responsible research and innovation	Inclusiveness of all participants	Balanced participation
		Fostering dialogue among participants
	Gender equality	Gender balance in participation
		Approaching critically gender issues
	Engagement	Emotional engagement
		Cognitive engagement

(*Continued*)

Table A2. Continued.

Categories Related to	Process requirements and learning outcomes	Subcategories Assessment criteria
	Ability to boost creative and critical thinking	Questioning and reframing
		Systems thinking
		Connecting topics with experience
		Seeking other points of view
	Inclusion of ethical issues	Understanding of the nature of science (NOS)
		Social relevance of topics addressed
		Participants acceptance of process/outcomes
		Connecting scientific topics with values
	Others	[Open category to other criteria]
Transversal competences	Learning to learn	Understanding the value of learning
		Learning autonomy
		Reflective thinking
	Social and civic competences	Communication skills
		Collaborative skills
		Respect for society and environment
		Informed and reasoned decision-making
		Ability to resolve conflicts
	Sense of initiative	Entrepreneurship
		Self-confidence and steem
		Ability to plan and manage projects
	Others	[Open category to other criteria]
Experiential aspects	Feelings and emotions	Enjoyment
		Emotional awareness and reflexivity
		Body and spatial awareness
		Empowerment and sense of belonging
	Perceptions and attitudes towards science	Attitudes towards science and the scientific issues approached
		Perceptions of science and the scientific issues approached
	Others	[Open category to other criteria]
Basic cognitive aspects	Acquisition of knowledge	Acquisition of conceptual knowledge
		Acquisition of tacit knowledge
	Others	[Open category to other criteria]

Note: Based on: Klassen et al. (2014), EC (2012a, 2012b and 2006).