Design and Evaluation of Teaching Materials for Responsible Research and Innovation

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ABSTRACT

The analysis of the classroom activities produced by a sample of 121 pre-service teachers provides evidence about the impact of a teacher professional development program to promote responsible research and innovation (RRI) through science education. Most of the activities produced by participants were related to curricular content knowledge, contributed to the development of key competences and defined learning objectives in line with current science education standards and RRI. Many of the classroom activities (78,6%) includes good or excellent maps of the controversy related to relevant socioscientific issues and high quality questions for scaffolding students' work. Additionally, 60,7% of the activities got high marks in the evaluation of authenticity and their potential to encourage science students' to make informed decisions and undertake an active role in societal issues concerning scientific and technological advances.

KEY WORDS

Science Education, Scientific literacy, Socioscientific Issues (SSI), Responsible Research and Innovation (RRI), Teaching resources.

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Conceção e Avaliação de Materiais Pedagógicos de Investigação e Inovação Responsáveis

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RESUMO

A análise das atividades em sala de aula produzida por uma amostra de 121 futuros professores apresentam evidências sobre o impacto de um programa de desenvolvimento professional do professor para promover a investigação e inovação responsáveis (IRR), através da educação em ciências. A maior parte das atividades produzidas pelos participantes estavam relacionadas com o conhecimento do conteúdo curricular, contribuíram para o desenvolvimento de competências essenciais e definiram objetivos de aprendizagem em linha com os padrões atuais da educação em ciências e da investigação e inovação responsáveis (IRR). Muitas das atividades em sala de aula (78,6%) incluem bons ou excelentes mapas de controvérsia relacionadas com questões sociocientíficas (QSC) relevantes e com outras questões pertinentes de apoio ao trabalho dos alunos. Além disso, 60,7% das atividades obtiveram pontuação elevada na avaliação da autenticidade e no seu potencial para incentivar os estudantes de ciências a tomarem decisões informadas e empreenderem um papel ativo no que diz respeito a questões societais relacionadas com os avanços científicos e tecnológicos.

PALAVRAS-CHAVE

Educação em ciências, Literacia científica, Questões sociocientíficas (QSC), Investigação e Inovação Responsáveis (IRR), Recursos didáticos.

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INTRODUCTION AND PURPOSE

Our 21th societies are facing major challenges: health and wellbeing, food security, sustainable agriculture; secure clean and efficient energy; smart, green and integrated transports, mitigation of climate change, environmental actions and sustainability, etc. (European Commission, 2017). Undoubtedly, many of the current societal challenges will require innovative solutions that have a basis in scientific research.

Science education plays a crucial role in the generation of well-prepared scientists to undertake the development and nurture the innovation that will be essential to meet the economic, social and environmental challenges that the world faces. Along with the preparation of future scientists, science education should promote scientific literate citizens able to actively participate in the debate of socio-scientific issues and make informed decisions in areas concerning the impact of human activities on the planet and the implications of scientific and technological advances.

Furthermore, in our technological and scientific societies it is necessary to ensure Responsible Research and Innovation (RRI). This term refers to the concern of making sure that the processes and products of science are well aligned with the values, needs and expectations of society (Burget, Bardone & Pedaste, 2017; Levinson, 2017). The participatory nature of RRI requires scientific literate citizens, who understand the nature of science and can discuss the risk and uncertainties associated with particular technological and scientific applications.

Scientific literacy as an educational goal may be defined by responding to the question 'What is important for young people to know, value and be able to do in situations involving science and technology?' (Organisation for Economic co-operation and Development, 2016, p. 18). In this line, some authors have discussed scientific literacy in relation to current challenges in science education and the pedagogical methods required to bring about the desired learning outcomes (Romero-Ariza, 2017).

After recognising the crucial role of science education in addressing the previously mentioned challenges, there is a need to further discuss which pedagogical approaches and teaching materials are appropriate to promote the knowledge, skills and dispositions required to actively participate in RRI and how can we best prepare teachers to bring them into the classroom.

Within the European project PARRISE (Promoting Attainment of Responsible Research and Innovation in Science Education), the main goal of this work is to discuss a science education model for RRI and to analyse the quality of a set of teaching materials according to this model.

THEORETICAL BACKGROUND

In this section we will draw on the specialised literature in order to define the main constructs involved in the science education model, which underpins the present work.

RESPONSIBLE RESEARCH AND INNOVATION

Responsible Research and Innovation has received increasing attention in academic publications and international projects such as RRI tools, IRRESISTABLE or PARRISE, after being a focus of interest in European Framework Programmes. Those programs intend to enhance cooperation between science and society and strengthening public confidence in a *science for and with society* (Geoghegan-Quinn, 2012).

In previous decades, ELSA in Europe (ELSI in the US), which stands for Ethical, Legal and Social Aspects of emerging sciences and technologies may be considered a precursor of RRI (Zwart, Laurens & van Rooij, 2014). ELSA studies meant to provide a social and ethical complement to major technology development programs and acknowledged that scientific expertise cannot be the sole basis for the development of new technologies. On the contrary, society should be involved from the offset to discuss risk and promote responsibility safety and security (Forsberg et al., 2015). Additionally, ELSA was supposed to bring about a more anticipatory approach that would focus on the processes of innovation rather than on the final products (Zwart et al., 2014).

Burget et al. (2017), in their literature review of 235 RRI-related articles found out that while administrative definitions were widely quoted in the reviewed literature, they were not substantially further elaborated. However they identified four distinct conceptual dimensions of RRI: inclusion, anticipation, responsiveness and reflexivity and added two emerging ones: sustainability and care.

Conceptualising RRI as a movement to promote science for and with society, Von Schomberg (2013) highlighted three 'anchor points': ethical acceptability, social desirability and sustainability. These anchor points can be recognised as the main aims of RRI to be accomplished through four key processes: diversity and inclusion, openness *and transparency*, *anticipation and reflectivity* and *responsiveness and adaptive change*.

In figure 1 we represent our understanding of the complex integration of RRI aims and processes.

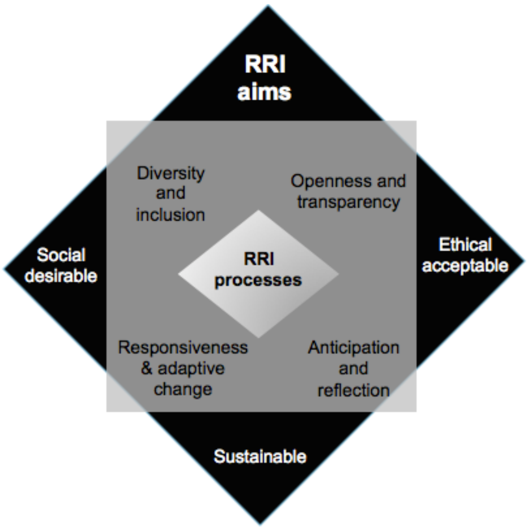

Figure 1. Aims and processes of RRI.

The aims and processes of RRI have been identified as an overarching context to design a science education model that could address those societal challenges (Levinson, 2017). We will take this overarching context as the referent point to shape educational interventions aimed at preparing individuals to actively contribute to RRI. The underlying science education model will be discussed in the following section.

A SCIENCE EDUCATION MODEL FOR RESPONSIBLE RESEARCH AND INNOVATION

In line with the European project PARRISE, we support a science education model for RRI that combines different pedagogical approaches: Inquiry-Based Learning (IBL), Socio-Scientific Issues (SSI) and Citizenship Education (CE). The model is known as SSIBL (Levinson, 2017). SSIBL stands for Socio-Scientific Inquiry Based Learning (SSIBL). The PARRISE project intends to empower teachers to enact such a model in order to equip their students with the knowledge, skills, values and dispositions necessary to actively participate in RRI.

The term Socio-scientific Issues (SSI) refers to problems that often arise in our world and have a scientific and/or a technological component. They are considered as issues or problems because there is no consensus on how they might be best solved and have inherent moral and ethical connotations (Levinson, 2006). To work on SSI, students have to identify and interpret data, to recognize different factors and effects and to take into account diverging opinions (Sadler, 2004). Examples of SSI are the use of human embryos, the production of genetically modified crops, the deployment of alternative energy resources, the environmental effects caused by socially useful materials or the climate effects caused by carbon dioxide emissions. The specialised literature shows that SSI increase students' motivation and engagement in science learning and offer powerful scenarios to develop critical thinking and the understanding of the nature of science and its implications (Lederman, Antink & Bartos, 2014; Sadler & Dawson, 2012; Vázquez-Alonso, Aponte, Manassero-Mas & Montesano, 2016; Venville & Dawson, 2010). SSI are easily recognised by students as real-world scenarios related to contemporary issues, thus bringing a sense of authenticity and relevancy to the science classroom. Furthermore, SSI can be approached through IBL, even though they might be seen as more comprehensive and complicated than scientific problems.

Inquiry-based Learning (IBL) has been advocated as an appropriate pedagogy to improve science education for decades (National Research Council, 2000, 2012; European Commission, 2007, 2015). There is research evidence of inquiry having a positive effect on students' interest in science (McConney, Oliver, Woods-McConney, Schibeci & Maor, 2014), the development of process skills and adequate view of the Nature of Science (Capps & Crawford, 2013; Lederman, Lederman & Antink, 2013), as well as the meaningful understanding of key science topics (Minner, Jurist Levy & Century, 2010).

As previously mentioned, the SSIBL model is based on three pillars: SSI, IBL and Citizenship Education (CE). Therefore, the other educational approach integrated in our science education model for RRI is citizenship education. CE takes into account the moral and social function of education and articulates the personal, interpersonal and the socio-political levels. This approach can make a relevant contribution to the education of critical, responsible and responsive citizens able to thoughtfully discuss SSI and support RRI. According to Veugelers (2001) critical-democratic citizenship education encompasses a learning process characterized by being:

- Reflective: individuals reflect on their own ideas and values and where they come from, as well as own their own learning process.
- Dialogical: learners discuss with each other, share different perspectives, and analyze social, cultural and political power relations.
- Democratic: individuals have concern for others and recognize the importance of building joint arguments and decisions.

The characteristics and main affordances of any of the described pedagogical components offer a resulting science education model with an interesting potential to address current societal challenges.

In the interpretation and enactment of the SSIBL model, we have placed special emphasis to three key features: authenticity, mapping the controversy in SSI and taking action.

Authenticity is related to the importance of linking education with current societal challenges and educating scientific literate citizens prepare for an active contribution to RRI. In the SSIBL model teachers are encourage to organise the learning process around authentic questions. According to the theoretical framework developed by Levinson for the PARRISE project, authentic questions include the following features. They:

- proceed from questions which interest and engage students (personal authenticity) and through which they express a wish, and choose, to find collective answers (social authenticity);
- involve real-world, complex, 'wicked problems' (Hipkins, Bolstad, Boyd & McDowall, 2014; Hume & Coll, 2010);
- are controversial in nature because there is often no overall agreement about solutions or even ways to frame the question;
- are questions or issues that emerge from young people spontaneously or, more likely, with sensitive support from teachers;
- presuppose change in that questions are asked about matters or issues which can be improved, e.g. made both more personally and socially desirable.

How such questions are raised is central to effective pedagogy in SSIBL and they can be initiated by discussing with students a recent new or a controversial issue affecting their lives.

Mapping controversy is related to individuals' capacity to explore a socio-scientific issue in an open way, taking into account different arguments (scientific, social, ethical, economical, environmental…); balancing benefits, risks and uncertainties; and evaluating conflicting points of views from different perspectives (individual/local/social). This description matches with several key processes in RRI: inclusiveness, open and transparency, and reflection and anticipation. Additionally, mapping the controversy is essential to ensure the three aims of RRI: social desirability, ethical acceptability and sustainability.

Finally, encouraging students to make informed decisions and take responsible actions is crucial to educate active and engaged citizens prepared to contribute to RRI.

In the following section, we will describe how we have drawn on this theoretical model to design a teacher professional development program. The aim of the course was to provide them with the knowledge and skills necessary to enact the SSIBL model, with a special focus on the design of teaching materials. We will describe the context and the sample of study, as well and the instrument and the method applied to evaluate the impact of the intervention on teachers' capacity to design good SSIBL classroom activities.

METHODS

In the following we describe the context, sample, instruments and methodology of analysis applied in the present study.

CONTEXT AND SAMPLE

The study was carried out with a sample of 121 pre-service teachers (65 female and 56 male), taking part in a 60 hours undergraduate course on science education, offered throughout a whole semester (from February to May). Participants were on their fourth year of a university program to become primary school teachers and had already had other subject on science education the previous year.

INTERVENTION

Participants in this study were subjected to an intervention based on a Teacher Professional Development (TPD) model previously validated (Ariza, Quesada, Abril & García, 2016). The TPD model has been specifically designed to equip teachers with the knowledge, skills and values necessary to promote Responsible Research and Innovation through science education and was consistent with the theoretical framework developed within the European project PARRISE.

The model entailed a wide range of teacher professional development activities, which encourage participants to adopt different roles: *teachers as learners, teachers as reflective practitioners* and *teachers as designers*. The TPD intervention consisted of 6 sessions of 2h each.

The two first sessions offered participants the opportunity to experience the educational potential of SSIBL as students. They were introduced to a SSI scenario and asked to inquiry, map the controversy, deliberate in small groups and present their results and conclusions *as learners* to the rest of the class. These two first sessions of the intervention respond to what is described in the specialised literature as an immersion TPD technique (Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003).

After the immersion experience, pre-service teachers were asked to take the role of *reflective practitioners* and identify the learning outcomes related to the SSIBL activity they were engaged as students. They were required to define the learning outcomes in terms of content knowledge and competences. A debate about the educational potential of this type of pedagogy compared to more traditional methods was then conducted.

The four following sessions were mainly focused on the development of specific teaching skills to design good classroom activities consistent with the science education model being promoted, a science education model aimed at equipping future citizens with the knowledge, skills and values necessary to actively contribute to RRI.

Before starting the design phase, teachers were provided with specific recommendations and quality criteria to guide the development of the SSIBL classroom activities: They were asked to have a look at the media and select a recent new dealing with a relevant socio-scientific issue, which could be of special interest to their future students. They should inquiry about the selected topic and map the controversy in order to identify key aspect to discuss, advance possible students' difficulties and prepare guiding questions to support effective inquiry and reasoning. Special emphasis was placed on the identification of different types of arguments (scientific, social, ethical, economical, environmental…), the evaluation of contrasting points of views (benefits/risks, individual/local/global) and the critical examination of bias and reliability concerning the sources of information.

Additionally, pre-service teachers had to look for specific links with the science curriculum, define learning outcomes and discuss how they would assess those learning outcomes related to the SSIBL activity being designed.

Finally they should describe how they would use this SSI scenario for promoting critical thinking, responsible decision-making and scientific literacy in their students.

Quality criteria concerning all the above-mention aspects of the design process were discussed with pre-service teachers in advance, and were later used for self-evaluation. Those criteria are part of the instruments applied for the analysis of the classroom activities designed by participants.

METHODS AND INSTRUMENTS

The classroom activities designed by participants were analysed using a qualitative approach involving two researchers. The analysis was conducted through successive cycles any of them involving first an independent analysis by each researcher and then a joint revision of results in order to refine categories, negotiate meanings and ensure inter-rater reliability (Silverman & Marvasti, 2008).

Initial categories were established in a deductive way to reflect the underlying theoretical model described in section 2.2. An instrument to evaluate the quality of contributions in any category was developed through iterative cycles of implementation and revision as described below:

The first cycle of analysis resulted in a 42% percentage of agreement between the two independent researchers. A revision of the way the quality criteria for each category had been defined resulted in a new version of the evaluation instrument. This revised version was applied to a new cycle of analysis, which produced 57% percentage of agreement between raters. The revision of the scale in the instrument and a new cycle of analysis resulted in 95% of agreement between raters. At this point, the instrument was validated and the remaining 5% of disagreement was resolved by discussion, reaching consensus. Table 1 shows the final version of the instrument used for the analysis of the SSIBL classroom activities designed by teachers.

Table 1

Instrument for the analysis of the SSIBL classroom activities designed by teachers

Category	Quality criteria
Authenticity	Good use of media (videos, ads…) to introduce SSI relevant to students. Well adapted to students' age and interests. Motivating/engaging. Positive and negative views.
Mapping Controversy	Related to scientific/technological advances and controversial. Different dimensions are analysed in an accurate/critical way (scientific, social, economical, environmental, health) Counter arguments are taken into account: it might include different interest's groups, evaluation of benefits/risks; individual/local/global) Critical stance concerning reliability and bias of information
Curriculum	Consistent and specific links to the school curriculum (Competences, standards, content…) Curricular elements are defined in an correct way Learning goals are consistent with the SSIBL approach
Assessment	Assessment criteria and processes are consistent with the learning goals and the SSIBL approach. Assessment criteria are defined (expressed) in an appropriate way.
Scaffolding	The questions for scaffolding: · draw attention on key aspects · advance potential students' difficulties and guide students · promote students' reflection and argumentation · are well formulated
Taking Action	Students are asked to conduct activities or make products that require informed decision making and/or action taken.
Evaluation	The self-evaluation results in concrete suggestions for the optimisation of most of the key features of the SSIBL model (relevancy, mapping controversy, scaffolding, curriculum, decision-making and action-taken…)

Note: According to the way quality criteria for each category are met, contributions can be described as: 1=non-existent/non-acceptable; 2=deficient; 3=acceptable; 4=good; 5=excellent.

RESULTS

The analysis of the artefacts produced by participants in our teacher professional development program provides evidence about the impact of the course on teachers' ability to develop SSIBL classroom activities. The classroom activities have been designed according to a science education model aimed at equipping future citizens with the knowledge, skills and values necessary to actively participate in RRI. In the following, we will discuss the main outcomes of the analysis conducted by two independent researchers applying the instrument described in table 1.

Participants selected a wide range of SSI topics based on recent news or controversial issues being discussed in the media. Two groups of participants selected climate change and zoos as the topic for their classroom activities, and three groups design activities related to pollution and environment. The rest of participants selected different topics. Table 2 shows the different topics chosen for the design of the SSIBL classroom activities analyses in this work:

Table 2

Topics selected for the SSIBL activities designed by pre-service teachers

Topics selected for the design of the SSIBL activities	
The blanket that cools in summer	Pollution in Madrid
Zealandia, the hidden continent	Cancer
For or against cow milk	About Kebab
Sugar and processed food	Hooked on sugar
Violent games	Zoos yes or no?
Implications of new technologies	Healthy food
The electricity bill	Pollution and environment
Coke	Cannabis yes or no?
Should zoos be banned?	Pollution
Wolves and their importance in ecosystems	Genetically modified food
Experimentation with animals	Thaw in Antarctica
Climate change: anthropogenic or natural?	Children à la carte
The discovery of a new planetary system	Tap water of bottled water?
Would you donate organs in life?	Climate change

Table 3 displays the results of the content analysis of the SSIBL classroom activities according to the categories and quality criteria of the evaluation instrument presented in table 1.

Table 3

Frequencies for each of the dimensions and categories analysed in the SSIBL classroom activities

	Frequency %				
Dimension/category	**Non-existent/ non acceptable**	**Deficient**	**Acceptable**	**Good**	**Excellent**
Authenticity	3.6	17.9	17.9	28.6	32.1
Mapping controversy	7.1	3.6	10.7	42.9	35.7
Curriculum	0.0	0.0	3.6	32.1	64.3
Assessment	3.6	25.0	25.0	21.4	25.0
Questions	3.6	7.1	10.7	42.9	35.7
Taking action	3.6	17.9	17.9	10.7	50.0
Self-evaluation	14.3	14.3	14.3	32.1	25.0

DISCUSSION

In the following we will comment on the main results starting by presenting the connection between the classroom activities designed by teachers and the Science Education Standards in Spain. Afterwards, we will discuss to what extent the teaching materials analysed meet the quality criteria related to the key aspects of our science education model: authenticity, controversy mapping and action taken.

The content analysis shows that the category best evaluated by experts is related to the identification of links with the existing curriculum. 96,4% of the activities got high marks being evaluated as good (32,1%) or excellent (64,3%) in this respect. Conversely, none of the tasks were considered deficient or not acceptable in relation to its connection with the school curriculum. Most of the activities produced by participants were related to curricular content knowledge, contributed to the development of key competences and defined learning objectives in line with current science education standards and the SSIBL model. This result is quite relevant considering that teaching is heavily curriculum-driven and an innovative pedagogy that cannot be aligned with existing curricula will be hardly sustainable. Additionally, it reveals that our TPD program has been successful in raising teachers' awareness of the educational potential of the SSIBL approach in terms of meeting curricular recommendations and standards.

In relation to authenticity, only 3,6% of the activities designed by teachers did not draw on media or relevant news to introduce the SSI to be investigated. This result reveals the emphasis placed on authenticity when developing a science education model for RRI. Authenticity is related to the importance of connecting science education with socio-scientific issues close to students' lives and daily experience. Teaching science focussing on those issues makes it meaningful and relevant to students. Inquiring on SSI provides students with interesting opportunities to better understand the foundation and implications of current scientific and technological advances and make subsequent decisions, what is closely connected to their potential contributions to RRI as informed citizens.

In this line, we have trained teachers in the use of media (news, videos and advertisements) to introduce SSI in the classroom and bring a sense of authenticity and relevance into the science classroom. Additionally, those resources may be used as a hook to introduce the topic and provoke students' engagement. The analysis of participants' artefacts shows that 60,7% of the SSIBL activities designed by pre-service teachers were considered as good or excellent concerning authenticity and relevance.

Teachers' capacity to map the controversy and prepare questions to support students' inquiry, reasoning and argumentation were also highly evaluated by experts. 78,6% of the classroom activities developed by participants include a good or excellent map of the controversy and high quality questions for scaffolding students' work. Controversy mapping requires individuals' capacity to explore a socio-scientific issue in an open way, taking into account different arguments (scientific, social, ethical, economical, environmental…); balancing benefits, risks and uncertainties; and evaluating conflicting points of views from different perspectives (individual/local/social). This description matches with several key processes in RRI: inclusiveness, open and transparency, and reflection and anticipation. Additionally, mapping the controversy is essential to ensure the three aims of RRI: social desirability, ethical acceptability and sustainability.

Responsiveness or action taken is the other of key features of the SSIBL model emphasized in our TPD course. We discussed with teachers the importance to educate responsible and engaged citizens able to take an active role in RRI by providing students with opportunities to take informed positions and responsive actions in relation to current SSI. As a result, teachers designed activities that encourage students to make videos and brochures to disseminate their informed opinions to the school, parents or local community, write letters to organisations and institutions or make concrete proposals about how to improve a particular aspect of their lives (their electricity bill, their sugar consumption, etc.). In this respect, our analysis shows that 60,7% or the classroom activities developed by the participants were considered good or excellent to support students in taking action about a particular SSI. These kinds of activities promote active and engaged citizens.

CONCLUSION

We have worked with a sample of 121 pre-service teachers in the development of classroom materials aligned with a science education model intended at equipping future citizens with the knowledge, skills and dispositions to actively participate in RRI. The science education model places special emphasis to three key aspects: authenticity, mapping controversies and taking actions. Based on the theoretical foundation of the model, the evaluation instrument validated (see table 1) and the results discussed in the previous section, we conclude that most of the classroom activities designed by teachers developed the three key features of the model in a good or excellent way, what is a relevant result considering current societal challenges and the need to educate citizens for RRI.

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