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Responsible Research and Innovation in science education: Insights from evaluating the impact of digital media and arts-based methods on RRI values

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Abstract

The European Commission policy approach of Responsible Research and Innovation (RRI) is gaining momentum in European research planning and development as a strategy to align scientific and technological progress with socially desirable and acceptable ends. One of the RRI agendas is science education, aiming to foster future generations' acquisition of skills and values needed to engage in society responsibly. To this end, it is argued that RRI-based science education can benefit from more interdisciplinary methods such as those based on arts and digital technologies. However, the evidence existing on the impact of science education activities using digital media and arts-based methods on RRI values remains underexplored. This article comparatively reviews previous evidence on the evaluation of these activities, from primary to higher education, to examine whether and how RRI-related learning outcomes are evaluated and how these activities impact on students' learning. Forty academic publications were selected and its content analysed according to five RRI values: creative and critical thinking, engagement, inclusiveness, gender equality and integration of ethical issues. When evaluating the impact of digital and arts-based methods in science education activities, creative and critical thinking, engagement and partly inclusiveness are the RRI values mainly addressed. In contrast, gender equality and ethics integration are neglected. Digital-based methods seem to be more focused on students' questioning and inquiry skills, whereas those using arts often examine imagination, curiosity and autonomy. Differences in the evaluation focus between studies on digital media and those on arts partly explain differences in their impact on RRI values, but also result in non-documented outcomes and undermine their potential. Further developments in interdisciplinary approaches to science education following the RRI policy agenda should reinforce the design of the activities as well as procedural aspects of the evaluation research.

Keywords: creative thinking; critical thinking; engagement; science learning

Introduction

The European Commission (EC) report on 'Science education for responsible citizenship' (EC 2015) raises the concern that conventional modes of science education exclusively focused on Science, Technology, Engineering and Mathematics (STEM) often fail in engaging European students' in science and fostering critical thinking, problem-solving and other skills they need to reasonably and responsibly apply scientific knowledge to real-world situations. Learning and teaching science in a non-integrated way, that is, without emphasising its social practices and applications to real-life challenges may affect the undertaking of scientific vocations negatively, particularly among girls (DeWitt et al. 2013; James 2017). To confront this situation, the EC is promoting the adoption of the Responsible Research and Innovation (RRI) concept as a guiding framework for science education research and practice. RRI has gained relevance and visibility within the EC policy context as a strategic approach to governing science and innovation through the lens of responsibility, transparency, inclusive deliberation and responsiveness to societal concerns (Owen et al. 2012). RRI is commonly defined as: "a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view to the (ethical) acceptability, sustainability and societal desirability of the innovation process and its marketable products (in order to allow a proper embedding of scientific and technological advances in our society)" (Von Schomberg 2011, p. 48). This emerging approach advocates the establishment of conditions enabling future citizens to actively participate in knowledge-based and science-informed decision-making relying on these fundamental values (Arnaldi and Gorgoni 2016), which places science education as one of the key RRI policy agendas (Klaassen et al. 2014).

The RRI agenda in science education is not re-inventing the wheel. It is acting as an umbrella of existing approaches and strategies that put more attention on critical skills and cognitive processes leading to students' active engagement in learning science and supporting scientific literacy, rather than being mostly concerned about gaining knowledge of facts (EC 2015; Kolstø 2001). For instance, RRI draws on the more recent framework for 21st century skills that links education with employability (EC 2015). At the same time it relies on the UNESCO humanistic approach to learning that advocates for an education based on inclusiveness beyond its utilitarian role in economic development (UNESCO 2015). RRI-based science education activities are thus expected to promote students' ability to think critically on societal challenges, respect others' ideas, collaborate with them and become able to participate effectively and responsibly in 21st-century societies. By focusing on skills, however, science education may detract attention from content knowledge acquisition that is necessary to understand how such knowledge is generated and why it is useful (National Research Council 2010). Further, it remains to be seen how RRI resolves the ambiguities of its approach regarding the links between science education and the market (i.e., public/social values and interests vs private/individual ones), which are typical of a rapidly evolving concept (Owen et al. 2012).

Notwithstanding these obstacles, progress has been made in outlining how RRI can achieve its agenda in science education (EC 2015). Under the lenses of RRI, inquiry-based learning strategies and activities are highlighted as useful for engaging students in science through the integration of content and process learning (Edelson 2001). In turn, educational research suggests that students' creativity, critical thinking and interaction may increase by opening up disciplinary boundaries from the prevailing focus on STEM

to a more interdisciplinary framework including 'All other disciplines' (STEAM) (Ulger 2016). Combining different disciplines (e.g., science education, humanities, Internet studies) to explain scientific concepts can provide other layers of meaning and make abstract and complex ideas more comprehensible to students (EC 2015; James 2017). Hence, teaching and learning methods relying on interdisciplinarity are seen as valuable to enhance scientific literacy, as the complexity of current socio-scientific issues requires multiple perspectives and knowledge frameworks for students to approach them and make sense of different kinds of information (Hurd 1998). Significant work has been done in promoting the use of digital media and artistic techniques in science education. These are suggested as potentially useful tools in enhancing pupils' problem-solving skills, creative and critical thinking and other RRI-related learning outcomes (EC 2015; Kampschulte and Eilert 2016). Previous research shows, for instance, that video games can effectively improve students' questioning skills and engage them in problem-solving, while enhancing their capacity to understand complex systems (Gee 2005). Drama-based approaches can provide pupils with rich and complex learning experiences through the enactment and embodiment of scientific concepts and stories. Students can stimulate their creativity, gain insights into science as a process and generate meaningful learning based on the dialogic interaction with their peers and the teacher (Odegaard 2003). However, putting in practice such interdisciplinary strategies and other RRI-related activities in formal education systems often requires that teachers and practitioners deal with time constraints and prevalent STEM curricula pressures for ensuring disciplinary rigour (Kaptan and Timurlenk 2012). These and other characteristic limitations, such as the lack of resources or specialised training, make the RRI agenda challenging to implement.

As noticed above, the RRI policy agenda is nevertheless being pushed forward in Europe. In terms of research, the design and examination of interdisciplinary learning and teaching methods for science classes, such as those based on digital media and arts, are being promoted by the EC (EC 2015). Therefore, analysing its impact on students' learning in terms of the expected RRI learning outcomes and process requirements deserves the academic and teaching communities' attention. Despite the rising interest in these techniques, what evidence exists on the impact of using digital technologies and arts-based methods in science education to promote RRI values remains an underexplored question.

The contribution of this analytical review is to inform the links between RRI and science education research from the evaluation of digital and artistic techniques with young people, which have both research and policy implications. Through a comprehensive review of 40 studies, we seek answers to the following research questions: RQ1) Do the reviewed studies evaluate the impact of digital media and arts-based methods on promoting RRI values in science education activities? RQ2) How are these evaluations conducted? RQ3) What is the reported impact of these activities on students' learning in terms of RRI-related learning outcomes? In doing this, we make comparisons between digital media and arts-based techniques, identify gaps and inform future research in the field of science education for responsible citizenship.

RRI values in science education

As a novel concept, the conceptualisation and operationalisation of RRI within the science education policy agenda, including its evaluation, is still under construction and evolving through new research. Efforts from the EC and related funded projects to frame

RRI in science education have mainly highlighted learning outcomes such as critical and creative thinking skills and students' engagement (EC 2012; Heras and Ruiz-Mallén 2017; Klaassen et al. 2014). Creative and critical thinking includes the ability to identify, understand and find imaginative ways to solve different and complex problems, potentially enabling young people to meaningfully participate in a knowledge-based society (OECD 2016). These skills also entail the ability to question and reframe scientific content adopting a systems-thinking perspective, seeking other viewpoints, and connecting topics with experience, to find the most appropriate ways to solve a problem (Ulger 2016). The promotion of creative and critical thinking skills can be done by engaging pupils in discussion and debates, in elaborating evidence-based opinions and decisions, and in anticipating science's unintended consequences, which are key RRI-related aspects (Okada 2016). In this context, engagement thus refers to those cognitive, emotional and behavioural resources needed to actively participate in science-based decision-making (Hampden-Thompson and Bennett 2013). We differentiate between cognitive engagement, which refers to students' interest and sustained attention during a task or process requiring mental effort, and emotional engagement, which relates to students' active implication and affective motivation in learning science (Woods-McConney et al. 2014).

RRI values in science education also seek to foster respectful and collaborative attitudes addressing different aspects of inclusiveness, including those related to gender differences (Heras and Ruiz-Mallén 2017; Klaassen et al. 2014). Inclusiveness refers here to the capacity of the educational activity and methods for reaching diverse students' profiles and backgrounds so as to avoid the exclusion of minorities and underprivileged groups from access to enriching learning experiences. Without entering in debates on the evidence (and lack of) about the existence of students' learning styles, research shows that the same kind of educational activities is not always optimal for every student in every context (Pashler et al. 2008). Different students' background-related factors, such as prior knowledge in a scientific domain, can limit their dialogue and collaboration for further learning (Gijlers and De Jong 2005).

Highly related to inclusiveness, RRI values also promote gender equality issues within science education activities. For instance, through process requirements ensuring gender balance in participation and a critical approach to gender issues (EC 2015, Heras and Ruiz-Mallén 2017). The gender gap in science fields has decreased in the last decades, but it remains a concern (OECD 2016). This gap can be explained by a complex and diverse set of factors including reduced opportunities for success in science girls perceive, gender stereotypes and other environmental factors such as teachers' and peers' views on gender issues related to science learning (Leaper et al. 2012). It can also be explained by scientific content that it is sometimes too male-oriented (Murphy and Whitelegg 2006), suggesting a low sensitivity to science education being linked to gender balance. RRI in science education thus advocates challenging this situation.

Finally, RRI acknowledges that both science and science education are not value-free, and therefore addressing ethical issues matter when learning about science (EC 2015). The integration of ethics in science education refers to the inclusion of values, interests and conflicting perspectives when teaching and learning science through, for instance, sharing ethical views and acknowledging uncertainties and contradictions of science (Okada 2016). This is related to increasing students' understanding of how science works, also addressing their capacity to discuss and reflect on the limits and strengths of science

and its social relevance, establishing connections with societal values (Osborne and Dillon 2008). Promoting such reflexivity and deep understanding of the scientific practice is critical in the development of teaching models aiming at science education for responsible citizenship (Kolstø 2001).

Based on this previous work, we build our analytical framework for this review on the five central documented RRI values guiding science education and its evaluation: 1) creative and critical thinking, 2) engagement, 3) inclusiveness, 4) gender equality and 5) ethics integration (Figure 1).

INCLUDE FIGURE 1 HERE

Methods

We conducted this review within the framework on EC Horizon 2020 project on science education using performing arts (PERFORM, www.perform-research.eu). The three authors of this article, researchers consistently trained within the framework of this project, conducted data collection and analysis following a review protocol, upon from which we discussed and agreed on both sampling criteria and categories.

We analysed 40 academic publications reporting science education activities using digital media (23), artistic methods (15) or both (2) (Table 1). These publications were selected because they met all the following criteria: 1) included empirical research, 2) examined science learning and/or engagement activities, 3) were based on digital media (i.e., activities using digital technologies such as web-based tools, video games, videos and computerized robots) and/or artistic methods (i.e., educational drama, role-game techniques, drawings and other methods related to artistic practices), 4) were conducted with students in primary, secondary and/or higher education, and 5) reported methodological details of the evaluation. To select these publications, we first performed a search in the Scopus scientific database, as it is the largest abstracts and citation database of peer-reviewed literature. To ensure the inclusion of studies explicitly reporting evaluation methodologies and results, we used the following key terms: TITLE-ABS-KEY (science learning OR science engagement) AND ALL (evaluation OR assessment) AND ALL (framework OR approach OR method OR perspective). We then reviewed the abstract of the 165 publications resulting from this search and, when needed, the whole text to discard those that did not meet the inclusion criteria. Twenty-three fulfilled the inclusion criteria (see Appendix, Table A1 for articles excluded). The other 17 were selected as relevant studies cited in these 23 papers, which also met the criteria. We are aware that our search for the review could be constrained by the keywords used and excluded studies published in articles not indexed in Scopus or in grey literature, which are limitations of our search.

INCLUDE TABLE 1 BY HERE

We combined directed and conventional content analysis (Hiesh and Shannon 2005) to respond to the questions guiding the review. First, we used a directed content analysis approach to answer the research question on whether the selected publications evaluated the impact of digital media and arts-based techniques on students' learning outcomes related to RRI values (RQ1). To do that, we drew upon the 5 RRI values and the corresponding 14 subcategories of our framework (shown in Figure 1), as guidance for codes. Data from the publications reporting on digital media and arts-based methods were

thus codified accordingly into these categories and subcategories as 1=presence and 0=absence of these RRI-related learning outcomes and process requirements. We then conducted conventional content analysis to answer RQ2. We identified coding categories emerging from the text data that referred to the methods used to evaluate the RRI values of each type of activity (i.e., digital media and arts): pre- and post-test, only post-test, interviews, observation, group discussions, other. We also used conventional content analysis to respond to RQ3 and, consequently, to examine the impact of these activities on students' learning in terms of RRI values. To do that, we identified coding categories emerging from the text data for the impacts of the digital media and arts-based activity related to each of the 5 RRI values of our framework. Finally, we also tabulated basic information on selected studies, including country, application context (formal, non-formal) and level of education (primary, secondary, university) for comparison purposes. We did not enter into the analysis of students' cultural differences or socio-economic backgrounds due to the difficulty to establish rigorous comparisons within our limited sample that includes different countries and levels of education.

Results

The majority of analysed studies (31 out of 40) reported RRI-related values when exploring the impact of science education activities. Specifically, 19 studies using digital media (out of 23), 11 employing arts (out of 15) and one involving a combination of both methods (out of 2) looked at one or more RRI values (Table 2). In what follows, we elaborate on these findings by addressing our three research questions concerning each RRI value introduced above. Therefore, we first report on whether the reviewed studies applying arts-based and digital methods addressed the RRI value or not (RQ1). We then look at how the evaluations in these studies were conducted (RQ2). We finally document the reported impacts on the RRI-related learning outcomes (RQ3).

INSERT TABLE 2 HERE

Creative and critical thinking

Creative and critical thinking was the most approached RRI value with a total of 25 studies, mostly in those using digital technologies (17). The effectiveness of the educational process in boosting students' ability to question and reframe science content was examined in 16 articles (9 on digital media and 7 using arts). Thirteen studies explored if and how students were able to adopt a systems' thinking perspective (9 using digital tools and 4 using arts). To a lesser extent, 5 and 4 studies on digital technologies and arts, respectively, assessed students' ability to establish a connection between the studied scientific topics with their daily experience. In turn, 5 studies on activities using digital media and one on arts evaluated students' capacity to ask for the opinion of their teachers and peers during the activities, as well as experts like researchers, to enrich their learning (RQ1).

In terms of the evaluation approaches applied (RQ2) and learning outcomes reported (RQ3), overall, the evaluation of science education activities using digital tools was more focused on examining students' changes in reasoning and problem-solving skills before and after the activity, often by relying on a control group. In turn, the analysis of activities using arts-based techniques, and particularly drama approaches, was more addressed to qualitatively explore differences in creative thinking between participant and non-

participant students. Science education activities using web-based tools (e.g., courseware, blogs, and forums) commonly relied on comparative study design to examine students' ability to propose and test hypothesis and/or conceptual questions, to engage in problem-solving, to establish complex relationships around a topic and to discuss and challenge peers' ideas. For instance, using pre- and post-surveys, interviews and focus groups, Wu and Huang (2007) found that secondary school students in Taipei attending student-centred classes where they used computer simulations to learn about force and motion made more reflections and focused more their discussions on the activities than their peers who attended teacher-centred classes. Kazmer (2011) also showed web-based tools effectiveness in fostering questioning and problem-solving. The author used post-tests and observations (without baseline or control group) to explore the impact of an e-learning experience with US information science master students to foster knowledge co-production through iterative feedback and on-line and off-line discussions. According to the research, students were able to explore unfamiliar contents and collaboratively apply acquired knowledge in real-world technological settings, which resulted in increased students' self-confidence and empowerment in the learning process. Pre- and post-test design was also used to examine students' ability to connect with their previous experience when using web-based tools or video games. Through these tests, a study in the UK explored if and how secondary school students were able to draw on their prior experience and scientific knowledge to make progress when using computer simulations to learn about science, which was shown to be a key learning factor (Rodrigues 2007). By contrast, in a study using video games, post-tests with intervention and control groups supported by observation showed no significant differences between secondary school students using this tool and those attending regular classes in their engagement in problem-solving when learning about genetics. Students in both groups did not differ in their ability to understand genetics concepts, connect these concepts with other lessons or content areas, or in their capacity to raise questions to the teacher and/or peers (Annetta 2009).

Interestingly, and differently from studies using web-based tools or video games, those about science education activities using videos, drama techniques and role-plays explicitly addressed creativity aspects mainly through qualitative evaluation methods such as observations, interviews and focus groups with both students and teachers. Research relying on interviews, group discussions and observation to analyse the learning outcomes of Australian primary school students when generating digital videos suggested that such experiential activity fostered students' conceptual and skill development related to technology and creative arts domains. They became aware of how they learned and reflected on their own learning while enhancing self-esteem and autonomy (Kearney and Schuck 2005). In the case of drama techniques, during group discussions, secondary school students in Hong-Kong reported they had developed their curiosity and learned to think broader through participating in these activities, which also strengthened their self-confidence (Cheng 2011). Hong-Kong students also reported they learned content but only a few spontaneously mentioned having acquired thinking abilities and strategies directly related to creative thinking skills, such as the ability to think from different perspectives or the use of metaphors to enhance understanding (ibid). By contrast, findings based on learners' self-reported answers from studies using drama techniques with primary school students showed different learning outcomes. For instance, informal discussions and interviews with UK students suggested they were aware that drama helped them in thinking of new ideas and identifying patterns related to science, among other creative thinking abilities (McGregor 2014). In the US, Varelas (2009) found the

use of drama techniques when teaching science fostered primary school students' ability to relate science content with students' daily, place-based experiences in a creative way, enhancing their understanding of the topic.

Engagement

Twenty-one studies assessed learning outcomes related to engagement, being approached in a similar number in those using digital media (12) and in those using arts (8). More specifically, cognitive engagement was examined in 10 of the studies using digital technologies, whereas emotional engagement was only assessed in 4 of these studies. In the case of artistic methods, 8 and 5 studies (out of the 8) examined cognitive and emotional engagement aspects, respectively (RQ1). Quantitative (e.g., pre- and post-test) and qualitative methods (e.g., observation) were used to analyse these learning outcomes in both digital media and arts-based science education activities. Criteria for examining engagement-related outcomes often overlapped with those referring to critical and creative thinking in activities using both types of techniques. (RQ2). The main reported impact of the evaluation of digital media was the improvement of cognitive aspects, such as students' ability to question and understand specific scientific topics. In turn, the evaluation outcomes of artistic techniques included as well emotional engagement aspects related to increased motivation and positive attitudes towards science learning (RQ3). The following examples of the studies reviewed further characterise these findings.

For instance, the above mentioned Cheng's (2011) long-term study with secondary school students and drama in Hong Kong used qualitative methods to analyse students' curiosity, appreciation of the activity and ability to solve science problems in original ways as proxies of creativity, emotional engagement and cognitive engagement, respectively. Similarly, when employing scientific caricatures in a higher education context with US geology students, cognitive engagement was measured through pre- and post-tests as their ability to understand, integrate and reason about knowledge on topics in a creative way, which was found to increase after the intervention (Clary and Wandersee 2008). Also, in a study with primary school students in Taiwan, Wang et al. (2012) examined students' cognitive engagement in a project-based learning initiative as their ability in questioning and sharing information through blogs, internet and power points, which also relates to critical thinking skills. Cognitive engagement was also approached as students' interest in tasks during the activity and in doing homework, which was found to increase when using these digital media tools.

Other studies combined quantitative and qualitative evaluation methods to gather data on both cognitive and emotional engagement. For example, pre- and post-tests supported by observation were used to examine the impact of combining digital and arts-based methods for learning physics on UK university students' cognitive engagement. Findings suggested that when the students were asked to generate graphs in a computer through their body movements their capacity to relate their body movement with the representation of motion in the computer increased their understanding of related physics more than when only observing (Anastopoulou et al. 2011). Also relying on multiple methods (pre- and post-tests, observation, interviews and group discussions) Taipei's secondary school students were found to make more reflections and to be emotionally more engaged in learning about force and motion when using computer simulations than when attending teacher-centred classes (Wu and Huang 2007). Interviews with pupils and

their teachers and classroom observation also showed that the use of puppets increased UK primary school students' motivation in learning science (Simon et al. 2008).

Inclusiveness

Process requirements related to inclusiveness were included in 16 studies, 8 using digital media and 8 using arts. All examined students' engagement in dialogue and sharing knowledge and ideas among themselves and with other participants during the activity. However, only 4 studies analysed inclusiveness by documenting the involvement of diverse students' profiles in the educational process (2 using digital technologies and 2 using artistic methods, RQ1). Regarding evaluation approaches (RQ2), a majority of studies employed mixed methods to examine inclusiveness, although the use of qualitative methods was prominent, particularly in those analysing the use of drama-based techniques. In all cases, reported impact was positive in terms of promoting inclusiveness and led to other learning outcomes such as increased self-confidence, social and communication skills (RQ3). In what follows, we include some studies illustrating these results. For example, the use of mixed methods to evaluate inclusiveness was done in two studies in Australia that successfully involved students in designing a role-play to model and learn about chemical reactions through conversation and discussion. Data gathered by such group discussions and observations during the activity, and debriefing meetings between teachers and researchers showed that role-plays promoted students' expression of their ideas with confidence and without fear of failure. This artistic method also enhanced students' participation in the group and their ability to interact with other peers (Aubusson et al. 1997; Aubusson and Fogwill 2006). Interestingly, only one study in our sample using digital media employed a qualitative research approach to assess, among other learning outcomes, those related to engaging in dialogue. Takayesu et al. (2006) asked students at Harvard Medical School to complete a free text commentary on the strengths and weaknesses of using computerised robots to simulate the clinical encounter and then coded their responses into emerging categories according to their learning outcomes. One of them was teamwork and communication since students valued the experience as an opportunity for practising their communication skills when working collaboratively.

As mentioned above, whether and how diverse students' profiles engaged in the educational experience was examined by few studies, mostly through observations and interviews with students. At primary school level in the US, Engle (2006) analysed the degree of involvement of the different pupils in the construction of biology-related content as a result of an inquiry in which they used, among others, electronic email. The study found that most interactive students were the ones who finally learned to construct graded and multicausal explanations on whales' endangerment. Also at primary school and relying on teachers' interviews, McGregor (2014) found that the use of theatrical techniques enhanced understanding of science among UK students with different learning abilities. For instance, the combination of cognitive resources with embodied ones (e.g. movement, gesture and positioning in the space) provided students with a diversity of resources to convey scientific meanings to and with their peers. This, in turn, helped some students with a lower ability level retain their learning.

Gender equality

Learning outcomes and process requirements related to gender equality were only examined in 4 cases, mainly through surveys. One study using digital technologies and other using arts examined gender balance in participation, while whether and how activities critically approached gender issues was analysed in one digital media study and 2 using arts techniques (RQ1). Tests were the primary evaluation method (RQ2), and results showed varied impacts according to the type of activity and learning outcome (RQ3).

For instance, to both address gender balance and critically approach gender issues, Clark and colleagues (2011) conducted a post-test with secondary school students in Taiwan and the US. Specific questions addressed pupils' achievement of learning outcomes by sex and their perceptions on the appropriateness of a digital game about physics for girls and boys. Results showed no difference in learning outcomes between girls and boys in both countries even though girls responded that they did not play digital games more often than boys did. By contrast, results related to the critical approach to gender issues differed among countries since US students perceived the game was more addressed to boys, whereas in Taiwan they thought it was more suitable for girls, suggesting the existence of cultural aspects informing students' beliefs about gender and digital games. Both gender equality aspects were also evaluated by Tveita (1998) through post-tests aiming to explore whether the use of role-games in science education helped reduce the gender gap when learning physics models. No case-control was included. Findings showed that both girls and boys engaged in the activity and gained an understanding of the topic, suggesting that girls might learn more physics by participating in activities using this arts-based method than from those employing traditional ones.

Integration of ethical issues

The integration of ethical issues was also examined to a minor extent: in 2 cases using digital technologies and 5 using arts (RQ1). While digital media techniques focused more on aspects related to their learning process, artistic ones used to approach the role of science in society. Qualitative and quantitative methods were used for evaluating students' understanding of ethical issues (RQ2). Regardless of the type of activity, students' increased awareness of ethical issues was reported (RQ3).

Specifically, the 2 studies on digital media analysed students' acceptance of the science learning process and outcomes. A Taiwanese researcg with primary school students used post-tests, interviews and group discussions to examine the impact of the use of blogs and other digital technologies as science learning tools in students' awareness on the ethical use of information found on the Internet and their perception on their ownership of outcomes (Wang et al. 2012). The authors found that students' autonomy over what and how to learn, for instance, by choosing their topic of interest, motivated them in science learning. Interestingly, the same study also reported students' lack of information literacy skills, connected to the lack of ethical considerations implied in students observed 'copy-and-paste' culture.

Students' understanding of the nature of science was only documented in 2 studies with activities using arts-based methods and analysed through quantitative methods with students (i.e., pre- and post-tests in Lau 2013) and mixed methods with students and teachers (i.e., questionnaires, observations, informal discussions, interviews, reflective journals in McGregor 2014). Lau (2013) also looked at the contextualisation of scientific

topics and research within societal challenges by using surveys, with a control group, and found that a role-play activity enhanced high school students' understanding of the role that science and technology can have in resolving societal challenges. This survey also included questions addressing students' technocratic and democratic views on socio-scientific decision-making to examine how they connected scientific topics with values.

Discussion

Through this review, we have explored if the reviewed studies evaluated the impact of science education activities using digital media and arts-based methods on promoting RRI values (RQ1), how these evaluations were methodologically approached (RQ2), and the impact of these activities on RRI-related learning outcomes (RQ3). While our results show that most of the analysed studies (31 out of 40) reported RRI-related values when exploring the impact of science education activities using both methods (RQ1), two other important findings deserve discussion. The first one relates to the differences identified in the focus (RQ1) and impact (RQ3) of the evaluation of digital media and arts-based methods in science education. The second one refers to the identified evaluation gap in terms of RRI values, which is connected with the methodological approaches employed (RQ2).

First, results from the reviewed literature suggest that both digital and arts-based methods are explicitly focusing on examining their potential contribution to support RRI values in science education referred to creative and critical thinking and engagement. Inclusiveness is also typically addressed in activities using both types of methods when referring to dialogic interactions with positive outcomes such as increased interaction and self-confidence (RQ1). Coherently, these studies seem to emphasise different impacts. In this way, reviewed studies using digital media typically focus on cognitive aspects and show their effectiveness in fostering students' problem-solving and reasoning skills while arts-based techniques commonly address and enhance curiosity, imagination and autonomy (RQ3). Reported differences in the focus and impact might be explained by how these teaching and learning methods are designed and applied with the students. Critical thinking and cognitive engagement require reflective decision-making and problem-solving (Dwyer et al. 2014). Video games, courseware and other web-based tools in the reviewed studies are commonly designed to stimulate problem-solving skills by guiding the students, often individually, in the collection of relevant evidence from previous analysis of available information on a scientific topic, and then engaging them in making reasonable decisions. Many reviewed activities using drama-based techniques are also based on inquiry-based learning and guide students through critical analysis, synthesis and problem-solving (Dorion 2011). Differently, digital tools are often expert-designed to engage students in an interactive but rigid learning process, whereas arts-based approaches are usually designed as more flexible and participatory learning methods aiming to foster students' exploration and other creative aspects. For instance, through drama-based methods, students are encouraged to create their learning developments and outcomes stimulated by the affective and embodied processing of scientific content (e.g. creation of metaphors using their bodies and movement) and by the interaction with their peers (e.g. through improvisation as showed by Nicholson 2005; McGregor 2014). Both methods might be complementary, but more research is needed to provide further evidence on their synergistic contribution to support RRI learning outcomes.

Furthermore, results suggest that the evaluation of the impact of science education activities using digital and arts-based methods on RRI values related to gender equality and the integration of ethics is overlooked (RQ3). Both are RRI process requirements, so the limited evidence of their evaluation might be because activities using digital technologies and arts do not tackle these aspects in their design. It is also possible that these aspects are overlooked because peer-reviewed publications use to focus on providing evidence on outcomes mainly related to students' cognitive and affective elements of learning. In this sense, a previous review on web-based learning in science education shows that few studies document gendered engagement patterns and participation preferences (Lee et al. 2011).

Second, the gap in addressing gender and ethical aspects might be due to the overall lack of appropriate evaluation methods to detect further complexities associated to these RRI values in science education (RQ2). This is in line with the challenge identified by science education experts to include continuing evaluation of activities that examine process requirements related to RRI as part of the educational practice for enhancing the quality of the teaching and learning process (EC 2015). In the case of gender equality, as seen in our review, critically approaching related aspects requires time-consuming methods, such as observations during the implementation of the activities (Clark et al. 2011). Our analysis also shows, however, that evaluation methods of rapid implementation can also be used when the design of the activities is sensitive to and critically approaches gender differences. This was done in Tveita's study (1999), in which he used post-tests to explore whether drama-based techniques (e.g. role games) helped in reducing the gender gap in learning physics. This evidence suggests that it is possible to go beyond the simple documentation of the number of girls and boys attending or performing well in an activity and analyse how gender, and possibly other socio-cultural aspects, interact with their learning of science. In this line, science education research can nurture from the analytic tools provided by the intersectionality framework to unravel factors behind gender inequality in STEM (Lyons et al. 2016). Including variables in assessments addressing different structural features of societies (e.g. in students' surveys through items considering gender, class and ethnic origin, among others, as noted by Harding and Norberg 2017) can contribute to identifying differentiated impacts according to students' profiles and interacting identities. By doing so, the evaluation can better grasp the capability of the educational process to reach the diversity of students in the classroom. This can provide valuable information to understand and to address negative attitudes and behaviours towards science such as those related to scientific vocations (Kaptan and Timurlenk 2012).

In turn, the contentious nature of some ethical issues in research and its associated complexity may challenge researchers to find adequate methods and techniques. This may imply conducting group discussions with students after their participation in activities or designing specific methods to examine their awareness of science contradictions and contrasting perspectives. It may also involve the employment of mixed methods such as observations, post-tests, before and after interviews, assignments and post-its on the blog, and informal conversations (Wang and et al. 2012). Although this is time-consuming in comparison to relying on only one data source, mixed methods provide with higher quality and richness of data by capturing the complexity inherent to the science learning process using interdisciplinary approaches. Also, the reviewed evidence shows that teachers can be key informants in the examination of the integration of ethical issues to complement researchers' observations during activities using both digital and arts-based

techniques and students' answers to interviews (Kearney and Schuck 2005; Dorion 2011). Formative evaluation methods can also support the process of both teaching and learning science, as highlighted by studies using drama in our review (McGregor 2014). More collaborative research involving teachers in the development of these tools could support the inclusion of ethical aspects in science learning and improve the overall effectiveness of the learning process (Akpinar and Bal 2006). Future work on the evaluation of RRI learning outcomes in science education can take advantage of these identified methodological opportunities. However, to be feasible in the current context of rigid science curricula in many countries, these innovative learning practices need additional resources, especially time for planning how to implement them (Cheng 2011).

Conclusion

This study was motivated by the still lacking evidence of the impact of science education activities using digital media and arts-based methods on students' learning concerning RRI values. By reviewing 40 selected studies, we have shed light on three interlinked research questions. First, our review suggests that RRI values related to creative and critical thinking, engagement and inclusiveness (when referring to dialogic interactions) are often addressed in science education activities using both types of methods. By contrast, gender equality and ethics integration are overlooked aspects. Second, it also provides new insights on the trends in the evaluation of science education activities using digital media and arts-based methods, mainly concerned with engagement and critical and creative thinking RRI values. Those studies relying on activities using web-based tools and other digital techniques seem to be more focused on examining how to enhance students' questioning and inquiry skills through mixed methods. Differently, imagination, curiosity and autonomy are more qualitatively addressed by studies looking at the use of arts-based methods in science education. Third, regarding the documented impact, digital media and artistic tools seem to be effective in promoting both cognitive and emotional engagement of the students. Nevertheless, the effects of employing digital technologies in science education are more related to improving problem-solving skills while the impact of arts-based methods, and particularly drama, relies heavily on creative skills.

Differences in the focus of the studies between those evaluating digital and arts-based techniques partly explain differences in their impact, but also result in non-documented outcomes and undermine their potential. This is the case of gender equality and ethics integration. How these RRI values can be increasingly addressed in the design, implementation and evaluation of science education activities using both digital media and artistic tools remains an underexplored question that deserves further research. It is essential to find out strategies for addressing these aspects because they entail process requirements for setting up the RRI policy agenda in science education. More importantly, they are key to ensure supportive and comfortable learning environments that provide all students, with independence of their sex and socio-cultural background, opportunities to engage proactively in science learning. To do that, the development of learning environments embracing science complexity, the reorientation of content-based curricula to focus on skills, attitudes and emotions, and the empowerment of science teachers with interdisciplinary tools for addressing gender and ethics more critically when teaching science can be strengthened. Science education activities can take advantage from the dialogic interactions and metaphors fostered by some digital media and arts-based methods to promote students' ability to questioning scientific evidence, relate

ideas, consider different perspectives and deal with science contradictions and contrasting perspectives.

To conclude, further developments in interdisciplinary approaches to science education following the RRI policy agenda should reinforce the design of the activities as well as procedural aspects of the evaluation research (also when approaching critical thinking and engagement). The results of this review also emphasise the need for more nuanced methodological approaches. Research interested in the RRI agenda in science education could thus explore appropriate evaluation methodologies able to capture the complexity associated to potential RRI values, and specifically those related to gender equality and the integration of ethics. We expect that further research can get inspiration from the findings of this review for entailing RRI values within science education research and practice.

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Table 1. Included studies in the review.

#	First author	Year	Title	Journal (J), Book (B) or Proceeding (P)	Number of students	Students' age (approx. y.o.)
1	Akpinar, Y.	2006	Student Tools Supported by Collaboratively Authored Tasks: The Case of Work Learning Unit	Journal of Interactive Learning Research (J)	69	12-13
2	Akpinar, Y.	2006	Teachers' collaborative task authoring to help students learn a science unit	Educational Technology and Society (J)	69	12-13
3	Anastopoulou, S.	2011	An evaluation of multimodal interactions with technology while learning science concepts	British Journal of Educational Technology (J)	18	19-20
4	Annetta, L.A.	2009	Investigating the impact of video games on high school students' engagement and learning about genetics	Computers & Education (J)	66	14-18
5	Aubusson, P.	1997	What happens when students do simulation-role-play in science?	Research in Science Education (J)	60 approx.	13-15
6	Aubusson, P.	2006	Role play as analogical modelling in science	Metaphor and analogy in science education (B)	15	16-17
7	Bailey, S	1998	Establishing basic ecological understanding in younger pupils: a pilot evaluation of a strategy based on drama/role play	International Journal of Science Education (J)	98	10-11
8	Braund, M.	1999	Electric drama to improve understanding in science	School Science Review (J)	37	19-20
9	Cheng, V.M.Y.	2011	Infusing creativity into Eastern classrooms: Evaluations from student perspectives	Thinking Skills and Creativity (J)	1200 approx.	13-15
10	Clark, D.B.	2007	Assessing Dialogic Argumentation in Online Environments to Relate Structure, Grounds, and Conceptual Quality	InterScience (J)	84	13-14
11	Clark, D.B.	2011	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 (J)	280	12-15
12	Clary, R.	2008	Scientific Caricatures in the Earth Science Classroom: An Alternative Assessment for Meaningful Science Learning	Science and Education (J)	193	Not specified (university)
13	Dorion, K.	2009	Science through Drama: A multiple case exploration of the characteristics of drama activities used in secondary science lessons	International Journal of Science Education (J)	174	11-15
14	Engle, R.A.	2006	Framing Interactions to Foster Generative Learning: a Situative Explanation of Transfer in a Community of Learners Classroom	The Journal of the Learning Sciences (J)	Not specified (1 school)	Not specified (primary)
15	Gobert, J.D.	2015	Using educational data mining to assess students' skills at designing and conducting experiments within a complex systems micro-world	Thinking Skills and Creativity (J)	101	14-15
16	Gold, A.	2015	Lens on Climate Change: Making Climate Meaningful Through Student-Produced Videos	Journal of Geography (J)	64	9-18
17	Harrower, M.	2000	Developing a geographic visualization tool to support earth science learning	Cartography and Geographic Information Science (J)	34	20.6 average
18	Kazmer, M.M.	2011	Produsage in a/synchronous learner-led e-learning	New Review of Hypermedia and Multimedia (J)	25-50	Not specified (university)
19	Kearney, M.	2005	Students in the Director's Seat: Teaching and Learning with Student-generated Video	Proceedings of Ed-Media: World Conference on Educational Multimedia,	Not specified (5 schools)	5-17

				Hypermedia and Telecommunications (P)		
20	Lamb, R.	2014	Cognitive diagnostic like approaches using neural-network analysis of serious educational videogames	Computers & Education (J)	500	9-12
21	Lau, K.C.	2013	Impacts of a STSE high school biology course on the scientific literacy of Hong Kong students	Asia-Pacific Forum on Science Learning and Teaching (J)	Not specified (2 classrooms)	14-16
22	Marques, I.	2014	Bioinformatics projects supporting life-sciences learning in high schools.	PLoS computational biology (J)	150	16-17
23	McGregor, D.	2012	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 (J)	200 approx.	5-7
24	McGregor, D.	2014	Chronicling innovative learning in primary classrooms: Conceptualizing a theatrical pedagogy to successfully engage young children learning science	Pedagogies: An International Journal (J)	425	8-11
25	Metcalfe, R.	1984	Teaching Science Through Drama: An Empirical Investigation	Research in Science & Technological Education (J)	21	10-11
26	Nyachwaya, J.M.	2011	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 (J)	110	Not specified (university)
27	Palmer, D.H.	2000	Using dramatizations to present science concepts. Activating Students' Knowledge and Interest in Science	Journal of College Science Teaching (J)	33	20-21
28	Rodrigues, S.	2007	Factors that influence pupil engagement with science simulations: the role of distraction, vividness, logic, instruction and prior knowledge	Chemistry Education and Research Practice (J)	24	14-16
29	Rowe, E.	2015	Serious games analytics to measure implicit science learning	Serious Games Analytics (B)	79	14-18
30	Sadler, T.D.	2015	Learning Biology Through Innovative Curricula: A Comparison of Game- and Nongame-Based Approaches	Science Education (J)	1888	14-18
31	Simon, S.	2008	Puppets promoting engagement and talk in science	International Journal of Science Education (J)		
32	Taagepera, M.	1997	Mapping students' thinking patterns by the use of the knowledge space theory	International Journal of Science Education (J)	5706	9-18
33	Takayesu, J.K.	2006	How do clinical clerkship students experience simulator-based teaching? A qualitative analysis	Simulation in Healthcare (J)	95	20-23
34	Tveita, J.	1999	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 (B)	209	12-15
35	Varelas, M.	2010	Drama activities as ideational resources for primary-grade children in urban science classrooms	Journal of Research in Science Teaching (J)	Not specified (6 classrooms)	6-8
36	Whitehouse, J.	2014	Evaluation of public engagement activities to promote science in a zoo environment.	PloS one (J)	1084	<16
37	Wang, C.	2012	Collaborative Action Research on Technology Integration for Science Learning	Journal of Science Education and Technology (J)	Not specified (1 class)	11-12
38	Williams, M.	2012	Exploring middle school students' conceptions of the relationship between genetic inheritance and cell division	Science Education (J)	209	12-13
39	Wu, H.	2007	Ninth-Grade Student Engagement in Teacher-Centered and Student-Centered Technology-Enhanced Learning Environments	InterScience (J)	54	14-15

40	Wui, L.S.	2008	An Evaluation of a Nutrition WebQuest: The Malaysian Experience	Eurasia Journal of Mathematics, Science and Technology Education (J)	12	13-14

Table 2. Number of studies addressing RRI values and related learning outcomes and/or process requirements.

RRI values	**Learning outcomes and process requirements**	**Digital**	**Arts**	**Both**
Creative and critical thinking		17	8	0
	Questioning and reframing	9	7	0
	System thinking	9	4	0
	Connecting topic with experience	5	4	0
	Seeking other viewpoints	5	1	0
Engagement		12	8	1
	Emotional engagement	4	5	0
	Cognitive engagement	10	8	1
Inclusiveness		8	8	0
	Balanced participation	2	2	0
	Dialogue among participants	8	8	0
Gender equality		2	2	0
	Gender balance in participation	1	1	0
	Critical approach to gender issues	1	2	0
Ethics integration		2	5	0
	Understanding of the nature of science	0	2	0
	Social relevance of topics addressed	0	1	0
	Acceptance of process and outcomes	2	0	0
	Connecting scientific topics with values	0	2	0

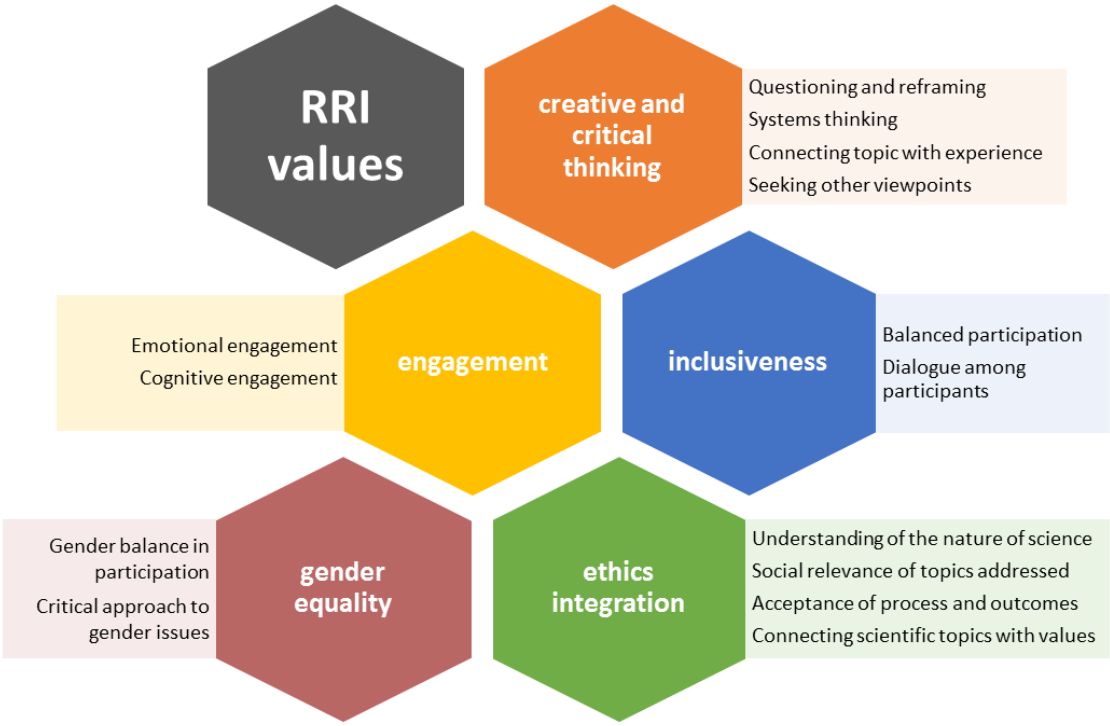

Figure 1. RRI values and related learning outcomes and process requirements guiding the analytical framework of this review (EC 2012, 2015; Klaassen et al. 2014).

Appendix

Table A1. Excluded studies in the Scopus search and reasons why.

#	Reference (First author, year, title)	Inclusion criteria that the study fails to meet					Comments
		Empirical research	**Science learning/engagement**	**Young people**	**Digital media/ arts**	**Assessment methodology**	
1	Onan, A. 2015 A fuzzy-rough nearest neighbor classifier combined with consistency-based subset evaluation and instance selection for automated diagnosis of breast cancer.		X	X			Evaluation of a breast-cancer diagnosis model
2	Giesbrecht T. 2015 Empowering front office employees with counseling affordances.		X	X	X		Face-to-face citizen service encounter in public administrations
3	Bulunuz, M. 2015. The Role of Playful Science in Developing Positive Attitudes toward Teaching Science in a Science Teacher Preparation Program.		X	X			Pre-service teachers' attitudes toward teaching science through play
4	Oyao, S. G., 2015. A Competence-Based Science Learning Framework Illustrated Through the Study of Natural Hazards and Disaster Risk Reduction.	X			X		Conceptual paper
5	Forbes C.T. 2015. Elementary teachers' use of formative assessment to support students' learning about interactions between the hydrosphere and geosphere.		X	X			Assessment focus on elementary teachers' use of formative assessment
6	Sabel J L. 2015 Promoting prospective elementary teachers' learning to use formative assessment for life science Instruction.		X	X			Preservice teachers' content knowledge and ability to engage in formative assessment practices for science
7	Forbes C. 2015 Integrating life science content & instructional methods in elementary teacher education.		X	X			Assessment of an innovative science course for elementary teachers
8	Hartley S. 2014 The challenges of consulting the public on science policy: Examining the development of European risk assessment policy for genetically modified animals.		X		X		Public engagement in science policy making
9	Csaki C. 2014 Towards the institutionalisation of parliamentary technology assessment: The case for Ireland.		X		X		Implementation of a formal parliamentary technology assessment (PTA) capability
10	Köksal M.S. 2014 Advanced science students' understanding on nature of science in Turkey.		X				Study of students' general understanding of science
11	Sarkar, M. 2014. Bangladeshi science teachers' perspectives of scientific literacy and teaching practices.		X	X			Study of science teachers' perspectives on scientific literacy
12	Tan, A. L. (2014). Mapping Curriculum Innovation in STEM Schools to Assessment Requirements: Tensions and Dilemmas.		X				It is focused on curriculum innovation
13	Täht, K. (2014). Learning motivation from a cross-cultural perspective: a moving target?.	X			X		It is focused on analysing PISA results
14	Contis, E.T (2014) Advancing Science, Engaging STEM Learners.						Not available
15	Pride, L. D. (2014). Using learning stories to capture "Gifted" and "Hard Worker" mindsets within a NYC specialized high school for the sciences.		X				Analysis of narratives around learning to improve STEM teaching in specialised schools

16	Sporea, A.(2014). Romanian teachers perception on inquiry-based teaching.		X	X		Analysis of teacher's perceptions of inquiry based methods at kindergarden level
17	Buldu, N. (2014). A Quality Snapshot of Science Teaching in Turkish K-3rd Grade Programs.		X	X		Focused on the quality of science teaching
18	Hsieh, T. C. (2013). Designing and implementing a personalized remedial learning system for enhancing the programming learning.		X			Assessment of a specific remedial learning system not of science learning
19	Čagran, B. (2013). Critical Self-Evaluation: An Attribute of Systemic Behavior: Authors of Natural Science Learning Materials as Evaluators.		X	X		Assessment of science learning materials by their the authors
20	Fleer, M. (2013). An assessment perezhivanie: building an assessment pedagogy for, with and of early childhood science learning. In Valuing assessment in science education: Pedagogy, curriculum, policy	X				Conceptual
21	Fensham, P. J. (2013). International assessments of science learning: Their positive and negative contributions to science education. In Valuing assessment in science education: Pedagogy, curriculum, policy	X				Review
22	Askew, M. (2013). Issues in Teaching for and Assessment of Creativity in Mathematics and Science. In Valuing assessment in science education: Pedagogy, curriculum, policy	X				Review
23	Fensham, P. J.(2013). Towards an authentically assessed science curriculum. In Valuing assessment in science education:	X				Review
24	Taylor, M. (2013). (Re) presenting disaster vulnerability in New Zealand school geography.		X	X		Its focus is on contrasting traditional and relational teaching approaches to vulnerability
25	Maida, C. A. (2012). Fundamentals: Building Communities of Practice in Comparative Effectiveness Research. In Comparative Effectiveness and Efficacy Research and Analysis for Practice (CEERAP)		X	X	X	Communities of practice in research and learning in health care
26	Elson, S. L. (2013). The Athena Breast Health Network: developing a rapid learning system in breast cancer prevention, screening, treatment, and care.		X	X		Patient centered approaches in research and communication of breast cancer
27	Murphy, C. (2013). Children's perceptions of primary science assessment in England and Wales.		X		X	The focus of the assessment is children's perceptions of the assessment, not their science learning
28	Nashon, S. M. (2013). Interpreting student views of learning experiences in a contextualized science discourse in Kenya.		X		X	Students' perceptions of Kenya's learning system
29	Lee, M. H. (2013). Proving or improving science learning? Understanding high school students' conceptions of science assessment in Taiwan.		X		X	Assessment of high-school students' perceptions of the assessment
30	Annetta, L. A.(2013). Science teacher efficacy and extrinsic factors toward professional development using video games in a design-based research model: The next generation of STEM learning.		X	X		Assessment of teachers' attitudes and efficacy through a professional development model

31	Milutinović, M. (2015). Designing a mobile language learning system based on lightweight learning objects.		X			It focuses on language learning through mobile apps
32	Buxton, C. A. (2013). Using educative assessments to support science teaching for middle school English-language learners.		X	X		It focuses on the impact of an assessment method in teachers' instructional decision making
33	Bell, P. (2013). Learning in diversities of structures of social practice: Accounting for how, why and where people learn science.	X				Conceptual article
34	Lay, Y.F. (2012) Relationships between actual and preferred Science learning environment at tertiary level and attitudes towards science among pre-service Science teachers, Pertanika			X		Assessment of pre-service Science teachers perceptions of learning environments and attitudes towards science
35	Park, S. (2012). Mapping out the integration of the components of pedagogical content knowledge (PCK): Examples from high school biology classrooms.		X	X		Evaluation of the degree of integration of pedagogical content knowledge by teachers within a pedagogical unit
36	Nelson, M. M. (2012). Preservice Elementary Teachers' Evaluations of Elementary Students' Scientific Models: An aspect of pedagogical content knowledge for scientific modeling.		X	X		It is focused on the approaches and criteria pre-service teachers use to evaluate student-generated scientific models
37	Pinto, M. (2012). Information literacy perceptions and behaviour among history students. In J. Broady-Preston, & L. Tedd (Eds.), Aslib Proceedings		X		X	It is focused on students' perception of their information literacy status and not in science learning
38	Lin, T.-C. (2012) A review of empirical evidence on scaffolding for science education.	X				Review
39	Tsai, M. J.(2012). Investigation of high school students' online science information searching performance: the role of implicit and explicit strategies.		X			Examination of students' online searching strategies and not their science learning
40	Smith-Jackson, T. (2012). Design of an inclusive science learning system for Appalachian children.		X	X		It focuses on designing inclusive STEM learning systems
41	Van Est, R. (2011). The broad challenge of public engagement in science.	X	X	X		Conceptual paper
42	Jensen, E. (2015). Highlighting the value of impact evaluation: enhancing informal science learning and public engagement theory and practice.	X				Review
43	Fan, L. (2014) Methods for improving the professional level of students majoring in information and computer science.		X	X		It is focused on teachers
44	Tekkumru-Kisa, M. (2015). A framework for analyzing cognitive demand and content-practices integration: Task analysis guide in science.		X			Assessment of science tasks and teaching, not of students' learning or engagement
45	Greenfield, D. B. (2015). Assessment in Early Childhood Science Education. In Research in Early Childhood Science Education	X				Review
46	Lu, Y. L. (2015). The application of the analytic hierarchy process for evaluating creative products in science class and its modification for educational evaluation.		X	X		Empirical case about a specific evaluation method of technological products. Focused on teachers.
47	Schultz-Jones, B. A. (2013). Evaluating students' perceptions of library and science inquiry: Validation of two new learning environment questionnaires.		X			Assessment of an assessment tool and not of students' learning

48	Neumann, K. (2013). Towards a learning progression of energy. Journal of Research in Science Teaching, 50(2), 162-188.		X			Assessment of an assessment tool and not of students' learning
49	Scanlon, E. (2012). Open educational resources in support of science learning: tools for inquiry and observation.		X			It does not include information on the evaluation
50	Mohan, B. (2006). Examining the theory/practice relation in a high school science register: A functional linguistic perspective.		X		X	The focus is on teaching practices and the analysis of the linguistic discourse
51	Lustigová, Z. (2009). A new e-learning strategy for cognition of the real world in teaching and learning Science.		X			No assessment or methods section
52	Olckers, L. (2007). Developing health science students into integrated health professionals: a practical tool for learning.		X	X		It explores two multiprofessional health care courses, no assessment methods
53	Shen, L. (2006). MutualBoost learning for selecting Gabor features for face recognition.		X			It is not about science learning/engagement
54	Klassen, S. (2006). Contextual assessment in science education: Background, issues, and policy.	X				Review
55	Harris, T.R. (2005). Challenge-based instruction in biomedical engineering: A scalable method to increase the efficiency and effectiveness of teaching and learning in biomedical engineering.	X	X			Review
56	Pringle, R.M. (2005). The potential impacts of upcoming high-stakes testing on the teaching of science in elementary classrooms.		X			Study on the impact of standardised testing in science teaching
57	Webb, M.E. (2005). Affordances of ICT in science learning: Implications for an integrated pedagogy.	X				Review
58	Xu, L. (2004). Advances on BYY harmony learning: Information theoretic perspective, generalized projection geometry, and independent factor autodetermination.		X			Analysis of the Bayesian Ying Yang harmony learning sytem not of students' science learning or engagement
59	Morejon, R.A. (2004). Advanced search algorithms for information-theoretic learning with kernel-based estimators.		X			It assesses the computational efficiency of algorithms in information-theoretic learning
60	Honkela, A. (2004). Variational learning and bits-back coding: An information-theoretic view to Bayesian learning.		X			It is focused on variational Bayesian learning
61	Choi, S. (2004). A negentropy minimization approach to adaptive equalization for digital communication systems.		X			Presentation and investigation of a new adaptive equalisation method
62	Wang, S. (2004). Learning mixture models with the regularized latent maximum entropy principle.		X			It presents a new approach to estimating mixture models
63	Cruces-Alvarez, S.A. (2004). From blind signal extraction to blind instantaneous signal separation: Criteria, algorithms, and stability.		X			Study on the problem of blind simultaneous extraction in mixture models
64	Sánchez-Montañés, M.A. (2004).A new information processing measure for adaptive complex systems.		X			It analyses a measure of information processing in adaptive systems
65	Rutkowski, L. (2004). Adaptive probabilistic neural networks for pattern classification in time-varying environment.		X			Study on probabilistic neural networks in non-stationary environments

66	Schraudolph, N.N. (2004). Gradient-based manipulation of nonparametric entropy estimates.		X		Methodological developments in non-parametric entropy estimations
67	Iwata, K. (2004). A new criterion using information gain for action selection strategy in reinforcement learning.		X		It focuses on informatics learning system developments
68	Sindhwani, V. (2004). Feature selection in MLPs and SVMs based on maximum output information.		X		Methodological developments in multi-layered peceptrons and support vector machines
69	Yamada, S. (2004). Recognizing environments from action sequences using self-organizing maps.		X		It explores action-based environment modelling developments
70	Yore, L.D. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research.	X			Review
71	Gribble, S.J. (2000). Negotiating values for the science curriculum: The need for dialogue and compromise.		X		Documentation of a process of incorporation of shared values into a science curriculum framework
72	Jerant, A.F. (1998).Training residents in medical informatics.	X	X		Review
73	Fernández, H. (1998). Concept mapping as a research tool: Knowledge assessment in social science domain.	X			Review
74	Norris, T.E. (1996). An educational needs assessment of rural family physicians.		X		Study of educational needs of rural family physicians
75	Reiner, M. (1995). Evaluation of a computer integration strategy in a science teacher's professional development program.		X	X	Evaluation of a teachers' training
76	Bacchus, C.M. (1994). A randomized crossover trial of quick medical reference (QMR) as a teaching tool for medical interns.		X		It explores the impacts of introducing QMR in medical professionals' training
77	Lewis, M. (1993). Assessing decision heuristics using machine learning.		X		Design of decision support systems
78	Barto, A.G. (1983). Neuronlike Adaptive Elements That Can Solve Difficult Learning Control Problems.		X		Focused on approaches using neuronlike elements to solve difficult learning control problems
79	Milford, T. (2010). National Influences on Science Education Reform in Canada.		X		It explores the influence of the Common Framework of Learning Science Outcomes
80	De Winter, J. (2011).'I no longer dread teaching physics, I now enjoy it!' Participant reflections from the SASP physics course.		X	X	It focuses on teachers participating in a physics course
81	Su, C.Y. (2010). The development of SCORM-conformant learning content based on the learning cycle using participatory design.		X		The focus is on the potential application of the 5E model to science e-learning materials
82	Chang, C-Y. (2010). A Major E-Learning Project to Renovate Science Leaning Environment in Taiwan.	X	X		Theoretical article
83	Lomas, D. (2007). Cognitive Artifacts: An Art-Science Engagement.	X			Theoretical article
84	Terrazas-Arellanes, F. E. (2013). English Language Learners' Online Science Learning: A Case Study.				Not available

85	Kruea-In, N. (2014). Enhancing lower secondary school science teachers' science process skills and laboratory lesson preparation through a social constructivist-based professional development workshop.		X	X		Assessment of teachers' science process skills and laboratory lesson preparation
86	Campos-Sánchez A. (2014). Motivational component profiles in university students learning histology: A comparative study between genders and different health science curricula.		X		X	Assessment focused on motivational component profiles
87	Haywood, B. K. (2014). Education, outreach, and inclusive engagement: towards integrated indicators of successful program outcomes in participatory science.	X	X	X		Review
88	Bowler, M. (2012). Assessing public engagement with science in a university primate research centre in a national zoo.			X		The target is the general public (visitors of the zoo) and not young people
89	Chankian, J. (2012). The study of curriculum utilization and science learning and teaching management in the context of community based environmental education, at Wang Pikul Academic Development Center, Petchaboon Primary Educational Service Area Office.		X			Study of curriculum utilization, science learning and teaching management.
90	Volkmann, M. J. (2005). The challenges of teaching physics to preservice elementary teachers: Orientations of the professor, teaching assistant, and students.		X	X		It focuses on an inquiry-based science instruction unit for teachers.
91	Martinez-Garza, M. M. (2013). Advances in Assessment of Students' Intuitive Understanding of Physics through Gameplay Data.		X			Analysis focused on the potential of a computer method for assessment, not in students' learning
92	Reagan, C. R. (1994). Ten years of basic medical physiology in the Mercer problem-based curriculum.	X				Review
93	Marchionini, G. (1994). Evaluating hypermedia and learning: Methods and results from the Perseus Project.		X			Evaluation of a learning project on the ancient Greek world
94	Galvão, C. (2011). Enhancing the popularity and the relevance of science teaching in Portuguese science classes.		X			Evaluation of teacher professional modules development
95	Ward, W. (2011). My science tutor: A conversational multimedia virtual tutor for elementary school science.		X			Assessment of Automatic Speech Recognition and semantic parsing components in an intelligent tutoring system
96	Neumann, I. (2011). Evaluating instrument quality in science education: Rasch-based analyses of a nature of science test.		X			It explores the validity of a specific NOS instrument
97	Penuel, W. R. (2011). Preparing Teachers to Design Sequences of Instruction in Earth Systems Science A Comparison of Three Professional Development Programs.		X	X		Evaluation of three professional development programmes, not on students science learning
98	Kudenko, I. (2011). Impact of a national programme of professional development in science education.		X	X		Evaluation of professional development programmes for teachers
99	Brenneman, K. (2011). Assessment for Preschool Science Learning and Learning Environments.			X		Pre-kindergarten science education
100	Keser, Ö. F. (2010). Assessment of the constructivist physics learning environments.		X			Evaluation focused on instructional models in learning environments

101	Orleans, A. V. (2010). Enhancing teacher competence through online training.		X		Evaluation of teachers' performance
102	Kali, Y. (2010). Curriculum design–as subject matter: Science.		X		It focuses on two design knowledge frameworks
103	Espinoza, F. (2009). Using project-based data in physics to examine television viewing in relation to student performance in science.		X		It analyses the impact of television in students' science performance
104	Wang, J. R. (2010). Preservice teachers' initial conceptions about assessment of science learning: The coherence with their views of learning science.		X	X	It analyses teachers' conceptions of science learning assessments
105	Speth, C. A. (2007). Using the ASSIST short form for evaluating an information technology application: Validity and reliability issues. Informing Science:		X		It assesses the validity of a measurement instrument to evaluate an information technology
106	Lehr, J. L. (2007). The value of "dialogue events" as sites of learning: An exploration of research and evaluation frameworks.	X	X	X	Review
107	Anderson, M. (2007). The status of machine ethics: a report from the AAAI Symposium.	X	X	X	Report summarising symposium discussions about machines ethics
108	Wilkes, L. (1999). Concept mapping: Promoting science learning in BN learners in Australia.				Not available
109	Wang, H. C. (2008). Assessing creative problem-solving with automated text grading.		X		It is an assessment of an automated grading tool to assess creative problem-solving
110	White, C. J. (2008). A fuzzy inference system for fault detection and isolation: Application to a fluid system.		X		Not about learning science
111	Cohen, E. R. (2008). Public engagement on global health challenges.		X		It is focused on broad public engagement in the developing world through an internet-based platform
112	Zhong, D. (2008). Face retrieval based on robust local features and statistical-structural learning approach..		X		It is a presentation of a framework to analyse face-retrieval based on local feature sets
113	Chilvers, J. (2007). Deliberating competence: Theoretical and practitioner perspectives on effective participatory appraisal practice.		X	X	It explores effective participatory appraisal for public engagement in science
114	Sattar Chaudhry, A. (2008). Enhancing the quality of LIS education in Asia: Organizing teaching materials for sharing and reuse.		X	X	It is focused on teaching materials and teachers' instruction, not on students learning
115	Penman, J. (2014). Addressing Diversity in Health Science Students by Enhancing Flexibility through e-Learning.		X		Assessment focused on several ICT instruments and not on students learning
116	Baxter, G. P. (1995). Using computer simulations to assess hands-on science learning.		X		Not focused on students' learning
117	Skoumios, M. (2011). Exploring Pupils' "Pathways" towards the Identification of Obstacles: The Case of Thermal Equilibrium.				Not available
118	Smeets, E. (2005). Does ICT contribute to powerful learning environments in primary education?		X		It is not about science learning or engagement
119	Welmar, H. G. (1996). Assessing the impact of computer-based learning in science.	X			Review
120	Appelbaum, P. (2001). Science! Fun? A critical analysis of design/content/evaluation.	X			Review
121	McSharry, G. (2000). Role play in science teaching and learning.	X			Theoretical paper

122	Leach, J. T. (2002). Designing and evaluating science teaching sequences: An approach drawing upon the concept of learning demand and a social constructivist perspective on learning.	X				Theoretical paper
123	Linfield, R.S. (1996). Can scientific understanding be assessed through drama?					Not available
124	Kamen, M. (1991). Use of creative drama to evaluate elementary school students' understanding of science concepts.	X			X	Review
125	Pugh, K. (2009). Motivation, Learning, and Transformative Experience: A Study of Deep Engagement in Science			X		No digital/arts-based methods
126	Woods-McConney, A. (2014) Science Engagement and Literacy: A retrospective analysis for students in Canada and Australia			X		No digital/arts-based methods
127	Bathgate. M. (2013). Children’s Motivation Toward Science Across Contexts, Manner of Interaction, and Topic			X		No digital/arts-based methods
128	Harris, C. (2005). Impact of Project-Based Curriculum Materials on Student Learning in Science: Results of a Randomized Controlled Trial			X		No digital/arts-based methods
129	Bathgate. M. (2015). The learning benefits of being willing and able to engage in scientific argumentation			X		No digital/arts-based methods
130	Jensen, E. (2014). Evaluating children's conservation biology learning at the zoo			X		No digital/arts-based methods
131	Fitzgerald, A. (2013). Embedding assessment within primary school science: A case study			X		No digital/arts-based methods
132	Stevens, S. (2013). Learning progressions as a guide for developing meaningful science learning: A new framework for old ideas			X		No digital/arts-based methods
133	Loukomies, A. (2013). Promoting Students' Interest and Motivation Towards Science Learning: The Role of Personal Needs and Motivation Orientations			X		No digital/arts-based methods
134	Hampden-Thompson, G. (2013). Science Teaching and Learning Activities and Students' Engagement in Science			X		No digital/arts-based methods
135	San Miguel, S. (2012). Fat dogs and coughing horses: K-12 programming for veterinary workforce development			X		No digital/arts-based methods
136	Brown, B. (2009). Conceptual continuity and the science of baseball: using informal science literacy to promote students' science learning			X		No digital/arts-based methods
137	Rivet, A.E. (2008). Contextualising Instruction: Leveraging Students' Prior Knowledge and Experiences to Foster Understanding of Middle School Science			X		No digital/arts-based methods
138	Etkina, E. (2010). Design and Reflection Help Students Develop Scientific Abilities: Learning in Introductory Physics Laboratories			X		No digital/arts-based methods
139	Chang, C.Y. (2006). Preferred - Actual learning environment "spaces" and earth science outcomes in Taiwan			X		No digital/arts-based methods
140	Jarman, R. (2005). Science learning through Scouting: an understudied context for informal science education			X		No digital/arts-based methods
141	Boddy, N. (2003). A trial of the Five Es: A referent model for constructivist teaching and learning			X		No digital/arts-based methods
142	Kozaitis, K.A. (1997) Partners in reform: "What's culture got to do with it?"			X		No digital/arts-based methods