THE PEDAGOGICAL POTENTIAL OF MULTIPLE REPRESENTATIONS IN A 21st CENTURY'S ELEMENTARY SCIENCE

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Abstract: Research on Multiple Representations (MR) has been ongoing for decades and demonstrated that MR has significant advantages for learning outcomes, since science requires the transformation of information from one form to another (for example, from equation to graphic or table), but little is understood about pedagogical potential of MR in a 21st century's elementary science. Science education, especially when instruction addresses the nature of science and promotes use of science practices, have a potential for developing 21st century skills, such as critical thinking, problem solving, and information literacy. Therefore, this article focuses on the potential of MR to support the developing of 21st century skills as students' engagement in science. By reviewing literatures in science education through searches of journal databases, we outline that through the use of MR in science education, we can support relevant 21st century skills, as literatures stated that MR has a potential to facilitate inquiry learning, especially in hypothesis generation and scientific reasoning. Additionally, it was found that scaffolded simulation-based inquiry learning with MR noticeably enriched students' science concept, therefore, it makes MR as an appropriate way to support elementary science in digital era.

Keywords: Multiple Representations, Science education, Elementary education, 21st Century skills

1. Introduction

In science education, in order to builds a more complete, deeper understanding of science; and communicates scientific ideas more effectively several information are presented in a particular form, and making a relation of each representations helps connect various aspects of a phenomenon (Danish, 2014)).

Multiple Representations (MR) could stated as various dimensions, such as different representational modes with different degrees of abstraction (like physical objects, photos, diagrams, graphs, texts, etc.), different scopes or representational levels (such as macro, micro, sub-micro, and symbolic), or different topics or content domains (that is, ecology, energy, evolution, etc.) (Treagust & Tsui, 2013). For the purpose of this paper, we focus on multiple representations as different representational modes.

Integration of hands-on science explorations with language arts skills have shown potential for increased learning in both subjects in elemntary science (Wilson, 2016). As an extension, science educators have become increasingly interested in the potential that using multiple modes of communication in science units has to promote deeper science conceptual understanding (McDermott & Hand, 2015). There is also growing recognition that constructing an multiple representation have a potential support inquiry learning (Prain, 2012; Kukkonnen, 2013; Chen, 2018).

Constructing representations is a critical aspect of several of the practices in the Next Generation Science Standards (NGSS) for early primary students (NGSS Lead States, 2013). Researchers have noted the important role that being able to interpret and construct representations of science knowledge plays in students' science literacy development (Prain & Waldrip, 2010). The NGSS practices related to scientific communication of developing and using models, analysing and interpreting data, and obtaining, evaluating, and communicating information each contain targets for K-2 students that involve them in constructing representations through images and text (NGSS Lead States, 2013). In addition, the practices of analysing and interpreting data and obtaining, evaluating, and communicating information for K-2 students encourage the sharing of science understandings through writing.

Nowadays, 21st century education demands a learning environment that able to enhance students' 4Cs (Collaboration, critical thinking, creativity, and communication) skill. To meet those demands, we suggest that inquiry as one of an appropriate way, through inquiry have usually mixed all kinds of information and data, concepts, and relationships, learning in such contexts often involves complex cognitive processes such as searching for information and data from multiple aspects, integrating information with domain knowledge, and generating a solution or explanation to the problem by reasoning with data that are intertwined in sophisticated ways. As stated earlier, constructing an multiple representation have a potential support inquiry learning, we argue this approach showed promising effects on 21st century's learning skill. But little is understood about pedagogical potential of MR in a 21st century's elementary science. Therefore, There is a need to further understanding of pedagogical potential of Multiple Representations to support students' learning in an environment in which scientific processes are valued as one of the fundamental aspects of science, and how do they related to enhanced students' 21st century skill, Communication, Collaboration, Critical Thinking, and Creativity

By reviewing literature in science education and integrating multiple perspectives, this article aims at exploring pedagogical issues and providing suggestions for integrating MRs in scientific processes. Specifically, we focus on, 1) how MR promote students' science conceptual understanding. 2) how MR facilitate inquiry learning, and 3) how MR enchance 21st century learning skill. This manuscript describes recent multiple representations studies by the science education research community including our own work in this field. we provide an outline of the recent trends in MR studies published between 2012 and 2018. These trends form a logical sequence. The sequence begins with the major question of whether using MR helps students learn concepts , based on the peer-reviewed articles published between 2012 and 2018, and how do these MR facilitate inquiry learning, especially in hypothesis generation and scientific reasoning . Concerning inquiry, what instructional innovations in order to support science learning in digital era actually help students use MRs while doing inquiry? And if they do use them, then how do they use them related to enhanced students' 21st century skill, Communication, Collaboration, Critical Thinking, and Creativity?

Preliminary inspection of the published literature revealed a diverse set of qualitative and quantitative research on the use of MR in science instruction. Therefore, since the objective of this study was to identify patterns and themes in a body of dissimilar studies with different methodologies, different contexts, and different research questions, a meta-synthesis rather than a meta-analysis was selected as the most appropriate way to review such disparate qualitative and quantitative studies (Rossman & Yore, 2009).

An electronic search of digital databases was conducted, with an additional parameter of publication dates between 2012 and 2018. While the search was not exhaustive, it was a systematic attempt to develop a conceptual review of the existing literature (Stake, 2010). An open coding procedure was applied to the final set of articlesin order to highlight date-sensitive trends and themes across the 6 years of publications. The analysis was undertaken to identify current areas of interest, emerging topics, and trends in MR research and highlight areas that might prove fruitful for further research.

To locate studies for inclusion in the thematic analysis, an electronic search of International journals databases (e.g. IJSE, JRST) was conducted using a variety of phrases (e.g. diagram AND science, representation AND science, and illustration AND science). The reference lists of items that were located during the electronic searches were carefully inspected. All items that were located during this phase of the search were reviewed to ensure that Multiple Representations were the topic of research, regardless of the terminology employed by the authors.

This step eliminated studies that focused on MR such as diagram, equation, graphic or table. The parameter of publication dates resulted in a set of articles reporting on 24 separate studies that examined the use of MR in science. If a study was reported on more than once, only the firstpublication was included in the review. All studies were published in peer-reviewed journals, and all studies were published in English.

Each study was categorised as Multiple Representations helps students learn science concepts (Trend A), Multiple Representations facilitate inquiry learning (Trend B), Multiple enhanced students' 21st century skill (Trend C). This final set of 3 labels was then used to re-code all 24 studies, to ensure that no research focus was missed and that all studies were coded using a consistent set of labels.

2. Multiple Representations promote students' science conceptual understanding

Many educators have investigated the impact of multiple representations (MRs) on students' learning of science (Won, 2014; Wilson, 2016; Lopez, 2017; Prain, 2012; Kukkonen,2013; Chen, 2018;Danish, 2014). Based on Ainsworth's framework (2006,2008) of three distinct functions multiple representations for learning, namely being complementary, constraining, and constructing.students who adopted extra strategies were able to reexamine their understandings and communicate them effectively and develop a coherent understanding of the concept.(won, 2014)

For learners to understand or explain concepts in science, they must use their current cognitive and representational resources to learn new concepts at the same time as they are learning how to represent them. Learning concepts in science involves students switching between verbal, written, visual, and mathematical (graphs, tables, equations) and three-dimensional representational modes, and coordinating these to generate explanations. There is a growing recognition that students need to acquire this competence in science discourse to achieve science literacy (Prain, 2012) and research by others in this area (diSessa, 2004; Ford & Forman, 2006; Lehrer & Schauble, 2006) suggest that this representational work has the potential to increase students' understanding of the form/function relationships in various representations, enabling students to understand the value and use of conventions in this work

An emerging idea is that the integration of multiple representations (image, text, physical models, etc.) into a science unit requires students to reconcile and fuse information into one constructed product, thereby increasing their understanding of the science content they are studying (Van Meter et al., 2006). Shah and Hoeffner (2002) that graphical literacy skills should be taught in the context of science, and also that translating between representations may be beneficial (from visual to verbal languages), and also explicitly focusing on the links between visual features and the meaning.

As many studies with different research subjects, in different countries, with different grades, has given the same results, that the MR can Promote students' science conceptual understanding (Won, 2014; Wilson, 2016; Danish & Enyedy, 2007; Lopez, 2017; Prain, 2012; Kukkonen,2013; Chen, 2018;Danish, 2014), even some studies have proven that the use of MR is effective in learning science in elementary school, for example ad hoc representations, such as sketches of flower pollination or the anatomy of a bee (Danish & Enyedy, 2007), are common in elementary science classrooms (Danish, 2014). Ad hoc representations are also frequently 'descriptive' representations (Ainsworth, 2006; Tytler, Prain, & Peterson, 2007), where the aim is to provide detailed information that aligns to teacher or discipline- based norms

Multimodal curricular units provide students with information in multiple representations from which they can synthesise their understandings in meaningful ways (Prain & Tytler, 2012; Van Meter & Garner, 2005; Wallace, 2004). Won (2015) findings provide evidence that multimodal learning in science units is beneficial even in lower primary-grade levels. Kukkkonen (2013) studies found The fact that after the instructional intervention the models were enriched with many relevant representations gives support to the assertion that it is important to use multiple representations when studying complex science phenomena.

3. Multiple Representations facilitate inquiry learning

Several studies have investigated the impact of multiple representations (MRs) on students' inquiry learning of science (e.g Kukkonen,2013; Chen, 2018). According to Quintana et al. (2004), inquiry is a process of posing and investigating questions, using empirical data from experiments or from other sources. Originating in scientific inquiry practices, inquiry learning involves students in exploring phenomena or problems by asking questions, collecting and interpreting data, constructing evidence-based arguments, and forming conclusions (Chen, 2018). Through collaborative inquiry activities, students acquire not only knowledge, but also discipline-related practices and reasoning skills (Hmelo-Silver, Duncan, & Chinn, 2007). Studies have indicated that inquiry learning is effective in fostering deeper and meaningful learning, improving academic achievement (Furtak, Seidel, Iverson, & Briggs, 2012), and developing problem-solving skills (Chen, 2018).

Kozma and Russell (2005) noted that students learn science effectively when they participate in activities 'in which representations are used in the formulation and evaluation of conjectures, examples, applications, hypotheses, evidence, conclusions, and arguments' Multiple representations have been employed to scaffold students' scientific reasoning, such as concept maps (Gijlers & de Jong, 2013), Multiple Representational supports have been proved to be effective in facilitating hypothesis formulation or reasoning. Representational guidance on reasoning also makes the formulation of hypotheses and logical reasoning salient (focusing student's attention on these activities) (Chen, 2018). The learner's active construction of representations related to a problem's solution has been found to promote deeper learning and improve learning processes and outcomes of inquiry learning and problem solving (Janssen et al., 2010; Suthers & Hundhausen, 2003).

The benefits of constructing an representation to support inquiry learning can be explained on the cognitive, metacognitive, and social dimensions (Chen, 2018). In the cognitive dimension, it assists with problem solving by reordering information in useful ways, facilitating inferences, focusing students on the construction of knowledge, and helping reduce cognitive load In the metacognitive aspect, it tracks the progress of reasoning through the problem and directs attention to the unsolved part of the problem. In the social aspect, it serves as shared cognition or as a discussion anchor that coordinates the discourse between peers during collaborative inquiries (Schwendimann & Linn, 2016). Additionally, constructing a shared representation facilitates consensus building because the representation stimulates discussion and argumentation (Chen, 2018). If learners have divergent ideas about a learning task, they must reach some kind of consensus to collaboratively solve it.

Wang, Wu, Kinshuk, Chen, and Spector (2013) proposed a computer-based integrated cognitive map that enabled students to externalize the reasoning process on a reasoning map and the knowledge underlying the reasoning process on a concept map when they worked with diagnostic problems. The approach showed promising effects on diagnostic problem solving

Ainsworth and VanLabeke (2004) saying that instructional simulations allow learners to make experiments. When observing the effects of these experiments, in many cases learners visualise features that often, by their nature, remain invisible. Furthermore, simulation almost always provides multiple representations which are characteristic of expertise and expert communication

Chen(2018) stated for the overall inquiry task performance shows that the groups in the experimental condition performed better than their counterparts in the control condition. This was consistent with previous studies (Janssen et al., 2010; Slof, Erkens, Kirschner, & Helms-Lorenz, 2013; Suthers et al., 2008), which also proved the effectiveness of representational support for group performance in solving complex problems

4. Multiple enhance students' 21st century leraning skill

21st century education requires the characteristics of students who have learning and innovation skills, related to critical thinking skills. As a result, we should design a learing environment that able to facilitate students to have the ability to ask questions and not be afraid to ask questions in an effort to develop critical thinking skills and problem solving. 21st century learning skills that built based on NETS-S, including 4c's (critical thinking, creative thinking, communicating, and collaborating). These skills are not content but skills to produce content.Therefore, Students in 21st century, have to be able demonstrate creative thinking behavior, build knowledge, and develop innovative products and processes using technology. Students have the skill in using digital media and the environment to communicate and work collaboratively (including remotely) to support individual learning and contribute to other learning. Related to multiple representations, Drawings have been a method to encourage student communication of their ideas in multiple science content topics, making them a valuable tool for assessment (Waldrip et al., 2010). When teachers enact tasks that involve drawing, they include different levels and types of support that impacts what students include in their science drawings.

Critical thinking skill as one of 4Cs skill, that is students have to be able use critical thinking skills to plan and conduct research, manage projects, solve problems, and make decisions using digital media and the right resources. This is one of the 21st century education requirement

That is students should have digital literacy skills and ICT literacy. Therefore students in the 21st century are those who have the ability to recognize, use technically, and utilize learning activities. Computer simulation for example, is also an ability of ICT literacy, therefore students can also be involved in audiovisual learning, related to MR, Computer simulations are considered tools that mediate and facilitate the relationship between reality and models or theories is the possibility of interaction between students' mental models on a certain topic and the underlying conceptual models in the simulation (Evagorou, Korfiatis, Nicolaou, & Constantinou, 2009) Additionally, the trend nowadays is that students are involved intensively in the process of web learning, including the use of interactive multimedia.

Smetana and Bell (2012) define simulations as computer generated, dynamic models of the real world and its processes. Simulations should according to them make scientific views more accessible, support contentbased instruction, and should be learner-centred and inquiry-based. Akpan (2002) states that simulations allow to repeat scientific procedures again and again, that in a conventional classroom setting would be too time-consuming or too dangerous, and Lindgren and Schwartz (2009) state that simulations do not only can scaffold inquiry, but also reduce the cognitive load imposed by mental manipulation of spatial topics Because of their interactive nature simulations hardly ever include dynamic representations and, besides, they usually include multiple dynamic representations (Ainsworth & van Labeke, 2004; van der Meij & de Jong, 2006). That is, simulations include moving objects, appearing and disappearing of objects, changing of the shape or the colour, plotting graphs, among others (Lopez, 2017). Several investigations have analysed the impact of this dynamism in students' comprehension of simulations. The 26 primary studies' review made by Höffler and Leutner (2007) states an instructional advantage of animation over static images, especially when animations are representational rather than decorative.

Eysink, et al. (2009) connect the use of simulations to inquiry learning, claiming that simulations are particularly suitable because they contain a model of a system or process which allows the learner to explore the phenomena by manipulating input variables and observing the changes Chang, Chen, Lin, and Sung (2008) combine aspects of scaffolding which, in several studies, have been found to be conditions for significant advantages in simulation- based inquiry learning. The first is to ascertain the level of background knowledge in order for learners to make a hypothesis. Second, it is important to help learners to make, evaluate and modify hypotheses while conducting experiments in simulation-based inquiry learning.

5. Conclusion

In this article, we discussed research on multiple representations in science education. In summary, we suggest the following issues that need to be considered and addressed by research on using multiple representations in elementary science. By reviewing literatures in science education through searches of journal databases, we outline that through the use of MR in science education, we can support relevant 21st century skills, as literatures stated that MR has a potential to promote science conceptual understanding,and facilitate inquiry learning, especially in hypothesis generation and scientific reasoning. Additionally, it was found that scaffolded simulation-based inquiry learning with MR noticeably enriched students' science concept, therefore, it makes MR as an appropriate way to support elementary science in digital era.

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