Ark of Inquiry: Responsible Research and Innovation through Computer-Based Inquiry Learning

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Abstract: Ark of Inquiry is a learning platform that uses a computer-based inquiry learning approach to raise youth awareness of Responsible Research and Innovation (RRI). It is developed in the context of a large-scale European project (http://www.arkofinquiry.eu) and provides young European citizens (7–18-year-olds) with a pool of engaging inquiry activities. Computer-based inquiry learning has been found effective in numerous studies. At the same time, several EU policy documents emphasize the need to increase society's active involvement in knowledge creation and scientific discussions. Therefore, RRI is a key term in the current policy of the European Commission. RRI is a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on the acceptability, sustainability and societal desirability of the innovation process. In the Ark of Inquiry project, we have developed a pedagogy that helps to link RRI to computer-based inquiry learning. In the current theoretical paper, we introduce this approach and explain how it has been implemented in the Ark of Inquiry project.

Keywords: inquiry learning, Responsible Research and Innovation, computers, science education

1. Introduction

According to various reports, young people are losing interest in science and less frequently regard science as their future career (e.g., Rocard et al., 2007). To ensure Europe's long-term capacity to innovate and conduct high-quality research, science education needs to become more engaging. It has been widely shown that inquiry-based science education (IBSE) increases learners' interest in science. Use of computers in IBSE further motivates young people and can support teachers in evaluating their learners' progress through learning analytics – the collection and analysis of data for adapting the next learning activities to the needs of (individual or groups of) learners. Another possibility of making science more engaging is to provide meaningful contexts for doing science. Therefore, the overall aim of the Ark of Inquiry project is to create a "new science classroom" that provides authentic opportunities for doing science. In the Ark of Inquiry project, a web-based platform is developed through which inquiry activities are made available for schools across Europe. Teachers in twelve countries across Europe are trained to help them implement the platform in their primary and secondary schools.

In recent years, Responsible Research and Innovation (RRI) has been an important focus in the European Commission to render science more meaningful for young citizens (Regulation (EU) No 1291/2013, 2013). Several large-scale projects have been financed to achieve a better understanding of what RRI is and how it could be realized (e.g., http://www.rri-tools.eu). Likewise, the Ark of Inquiry project seeks to promote RRI awareness and skills. However, the definition and pedagogies of RRI have not been developed in depth yet (Stahl, McBride, Wakunuma and Flick, 2014). The aim of this paper is to show how the Ark of Inquiry project defines RRI and relates it to computer-based IBSE.

2. Inquiry learning

Inquiry learning is an educational approach of discovering knowledge through formulating and testing hypotheses by conducting experiments and/or making observations (Pedaste, Mäeots, Leijen and Sarapuu, 2012). Active and self-directive participation of learners is central (e.g., Wilhelm and Beishuizen, 2003). Inquiry learning is usually divided into phases of scientific thinking that together make up the inquiry cycle. A variety of inquiry cycles can be found in the literature (e.g., Bybee et al., 2006; White and Frederiksen, 2000). A systematic literature review conducted by Pedaste et al. (2015) identified the core features of inquiry cycles, resulting in an inquiry cycle that combines the strengths of all existing inquiry learning frameworks and comprises five major phases. In the Orientation phase, curiosity about a topic is stimulated, resulting in a problem statement. In the Conceptualization phase, research questions and/or hypotheses are stated. In the Investigation phase, empirical data is gathered and processed to resolve the research questions or hypotheses by exploration or more structured experimentation, leading to the Data Interpretation sub-phase. In the Conclusion phase, research findings are reported. Finally, in the Discussion phase, the outcomes of the inquiry are communicated and the inquiry (sub)processes evaluated.

3. Responsible Research and Innovation

"Responsible Research and Innovation" (RRI) is fundamentally an attempt to re-imagine research and innovation and redefine the relationship between the social sciences, humanities, and technosciences (cf. Felt 2014; Levidow and Neubauer, 2014). Current research on RRI evolved from the definition provided by René von Schomberg (2011), who defined RRI as "a transparent, interactive process by which societal actors and innovators become mutually responsive to each other with a view on 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)" (p.9). In recent years, several other authors have further contributed to the conceptual development of RRI and its applications (e.g., Owen et al., 2012; Stahl, 2013; Stilgoe, Owen and Macnaghten, 2013).

Promoting RRI awareness is a key factor in the Ark of Inquiry project. In the project, RRI is defined as "the attitude and ability to reflect on, communicate and discuss processes and outcomes of inquiry in terms of its relevance, consequences and ethics for oneself, others and society". Three main RRI actions are present in this definition: reflection, communication, and discussion. The act of reflection is dedicated to developing the attitude and ability to *individually think through* the relevance, consequences and ethics of inquiry. The act of communication refers to the attitude and ability to *present and explain* the relevance, consequences and ethics of inquiry to an audience. Finally, the act of discussion refers to the attitude and ability to further *question and discuss* the relevance, consequences and ethics of the processes and outcomes of inquiry with an audience.

RRI awareness is promoted through several means in the project. First, a Framework of Inquiry Proficiency and an Evaluation System were developed that enable teachers and learners to assess their skillfulness in doing scientific inquiry; RRI aspects (reflecting, presenting, and discussing) are included in the Discussion phase of the framework. Second, an Award System was developed which is particularly aimed at promoting RRI awareness and skillfulness. Third, support is provided to teachers for promoting RRI awareness in the existing inquiry activities.

4. Ark of Inquiry pedagogy and platform

In the Ark of Inquiry project, we have developed a pedagogy that helps to link RRI to computer-based inquiry learning. A Framework of Inquiry Proficiency, an Evaluation System and a related Award

System as well as Pedagogical Scenarios for supporting teachers have been created. The framework and supporting systems have been integrated into an online learning platform in which existing inquiry activities are collected and offered to learners across Europe for the purpose of learning science and learning to do science.

4.1 Inquiry proficiency levels

The Ark of Inquiry project seeks to challenge learners to increase their inquiry proficiency. For this purpose, a Framework of Inquiry Proficiency was developed that helps to categorize inquiry activities and determine learners' inquiry capabilities. Three levels are distinguished between in the framework: A (novice), B (basic), and C (advanced). The levels categorize inquiry activities according to how they challenge a learner to exhibit increasingly complex inquiry behavior defined across three dimensions: problem-solving type, learner autonomy, and learner awareness of RRI. In the framework, all dimensions are linked to the five phases of the inquiry cycle (Table 1).

In the first dimension characterizing inquiry proficiency, inquiry activities are divided into two types: well-defined or ill-defined problems (Robertson, 2001). A well-defined problem has a clear path to reaching a solution, and the solution itself has been thoroughly established as a scientific fact. An ill-defined problem does not suggest an obvious path to a solution, and a 'correct' solution is not necessarily prescribed beforehand. Increased proficiency according to this first dimension moves from well-defined to ill-defined problems.

Degree of learner autonomy is the second dimension. In case of novices, inquiry is initiated and led by the teacher and/or by the materials so that learners become familiar with the method of scientific inquiry. As learners progress, the teacher guides the inquiry process less and less and the learner moves from structured to guided inquiry and finally to open inquiry (cf. Colburn, 2000). The progression is associated with self-regulated learning, where learners themselves increasingly take control of the learning process.

Learner awareness of RRI is the third dimension. In this dimension, inquiry activities gradually expand the amount and type of interaction learners have with other learners and/or stakeholders in order to explore and include different perspectives. For example, basic inquiry activities take place within the school setting involving only their teacher and peers, but progression in inquiry requires gradually expanding the scope of societal stakeholders a learner interacts with, for instance, through work visits on off-school premises or social media platforms. A developed sense of RRI allows a learner to communicate, explain and discuss the relevance and consequences of research and research findings to people and society.

Table 1. Framework of Inquiry Proficiency

INQUIRY PHASE	INQUIRY PROFICIENCY LEVEL		
	A (novice)	B (basic)	C (advanced)
ORIENTATION	Learners are introduced to a problem within a well-defined problem space.	Learners are introduced to a problem in a semi-structured problem space.	Learners identify a suitable problem in an open-ended problem space.
CONCEPTUA-LIZATION	Learners are led to common questions and/or hypotheses that will be studied in the investigation.	Learners formulate questions and/or hypotheses through guidance.	Learners explore and formulate meaningful questions and hypotheses.
INVESTIGATION	Learners collect and analyze data according to prescribed procedures and fixed instruments.	Learners collect and analyze data in semi-structured steps and formats.	Learners operationalize procedures and formats through which they collect and analyze data.
CONCLUSION	Learners reach an understanding of fixed conclusions.	Learners reach conclusions through (semi-)structured procedures.	Learners reach conclusions and explain the process.
DISCUSSION	Learners present in fixed formats to teachers and/or peers.	Learners present and communicate in semi-structured formats to teachers and/or peers.	Learners present and discuss at appropriate times and in applicable formats with diverse stakeholders.

4.2 Evaluation and awardance of inquiry proficiency and RRI awareness

The function of the Evaluation System in the Ark of Inquiry is twofold. First, it monitors the progress learners make in doing inquiry across three levels. Across those levels, learners become better in the so-called transformative inquiry skills, such as formulating hypotheses, collecting data, and interpreting data to reach evidence-based conclusions (Pedaste and Sarapuu, 2014). Second, the Evaluation System evaluates scientific inquiry and RRI awareness by assessing regulative (metacognitive) skills such as planning, monitoring and evaluating the inquiry process (de Jong and Njoo, 1992). Next, the three principles of the Evaluation System and the evaluation forms that spring from them are described.

The first principle is personalized learning, defined as an emerging pedagogy that takes differences between learners as a starting point to tailor education to their needs. Personalized learning aims at solving some structural problems in the educational system that are often associated with standardized learning settings, such as low effectiveness and success rates, low motivations, and underestimation of talents (e.g., Robinson, 2009). Following from this principle, the Evaluation System emphasizes formative assessment and uses a format for formative dialogue to reflect on the inquiry activity, the learner's performance, and the next challenge.

The second principle is self-regulation, defined as 'a systematic process of human behaviour that involves setting personal goals and steering behaviour toward their achievement' (Zeidner, Boekaerts and Pintrich, 2000, p. 751). Self-regulation is about giving control to the learner and is claimed to be beneficial for a learner's sense of autonomy, motivation and, subsequently, learning outcomes (Ryan and Deci, 2000). Proceeding from this principle, the Evaluation System uses self-report. In the self-report, learners write down what they have been doing, what they have learned and which questions they have after finishing the inquiry activity.

The third principle is becoming part of a community of learning, defined as a group of learners that share a learning purpose and meet (ir)regularly either live or through a platform to share and support each other (see Wenger, 1998). The Ark of Inquiry will be used by thousands of learners, thus creating a sense of becoming part of a community of learners. Based on this principle, the Evaluation System uses peer feedback on inquiry processes and products.

The Evaluation System sets the stage for structured and formative reflection on the process and outcomes of scientific inquiry. Learners collect inquiry products, learner reports, formative assessments and peer feedback in a personal portfolio. This portfolio presents an overview of a learner's progress as well as collects proof for passing summative level tests. On top of that, an Award System is embedded in the Ark of Inquiry that explicitly promotes and celebrates RRI activities and products. Learners who explore the relevance, consequences and ethics of scientific inquiry collect their RRI products in their portfolio and can get nominated and awarded by their teachers and/or peers. Awards include a star and diploma for outstanding individual reflection and presentations to small audiences and subsequently a bronze, silver and gold medal for excellent large-public debates on the RRI aspects of research. The collected awards become part of a learner's portfolio.

4.3 Pedagogical scenarios

In the Ark of Inquiry project, pedagogical scenarios were designed to help teachers implement, adapt and reuse inquiry activities in their classrooms. The need for the scenarios stems from the fact that in the Ark of Inquiry, existing inquiry activities are collected which, for instance, do not always contain all inquiry phases or include RRI aspects. The scenarios help teachers re-design the existing activities so that they better fit the Framework of Inquiry Proficiency, relate to RRI goals, and improve the exchange of activities across countries and educational contexts. Six pedagogical scenarios have been developed so far.

The first scenario introduces the inquiry model of the Ark of Inquiry and, in particular, its inquiry cycle and shows how other inquiry models used by teachers can be linked to the inquiry cycle used in the Ark of Inquiry. The second scenario is for changing the difficulty level of a particular inquiry activity. For instance, the teacher can either reduce or increase the structure and scaffolding, thus giving more or less initiative to learners. The third scenario is for improving the existing inquiry activities by adding missing phases. The fourth scenario aims to support attracting more women to science and science careers. Girls' negative views and low self-efficacy in science are often associated with characteristics of the learning environment that do not motivate and engage girls (e.g., Kim and Lim, 2013). The scenario helps teachers provide activities which connect to contexts that are more engaging for girls and supports the presence of female role models in or around the activities. The fifth scenario is meant for overcoming language dependency issues by showing teachers that the language dependency of activities widely varies and does not need to be an obstacle (for instance, in visually oriented learning environments) or could even turn into an advantage when combined with foreign language learning.

In the Ark of Inquiry project, special attention is paid to enhancing the RRI awareness of learners. Therefore, the sixth pedagogical scenario focuses on linking the existing inquiry activities with the RRI approach to scientific inquiry. Because the inquiry activities used in the Ark of Inquiry platform already exist, they do not always explicitly incorporate RRI or the RRI aspects could be elaborated on or made more explicit. For that purpose, teachers need to be able to recognize the RRI aspects in the existing activities and should be supported in adding or elaborating on an RRI aspect in the existing activities (e.g., by giving examples of RRI assignments, public debates or videos). Moreover, teachers should be guided in adapting RRI aspects so that they fit their classroom pedagogies.

4.4 The Ark of Inquiry platform

Within the Ark of Inquiry platform, the inquiry activities are presented as a library of activities, allowing potential users to scroll through the list of activities, search for activities using a search function or select an activity based on keywords. In addition, teachers can suggest or assign activities to learners based on levels of proficiency. All activities included in the platform are in line with the pedagogical framework of the Ark of Inquiry. The information (i.e. metadata) on each activity that will be available to the users includes the following: title of the activity, description, location (web-based or physical location), domain(s), topic(s), language(s), overall proficiency level of the activity, inquiry phases covered, age range, learning time, materials needed, and evidence on the success of the activity.

The initial version of the Ark of Inquiry platform contains a total of 68 activities. These can be accessed through the platform and implemented, adapted and reused worldwide in classrooms, at home and in science centers and museums. The repository of activities represents a good coverage of the central components of the project and provides a fruitful baseline for a small-scale pilot.

5. Conclusion

In conclusion, we can say that the Ark of Inquiry project aims at finding a new pedagogy to link inquiry learning with RRI in the context of computer-based education. Teachers are a key factor in reaching the goals of the project. Therefore, our efforts in the near future focus on supporting teachers in starting to use the Ark of Inquiry in two ways. First, teachers will be provided with web-based materials helping them orient to inquiry learning in general and RRI in particular. Through the web-based materials, teachers get to learn the Framework of Inquiry Proficiency and the Evaluation System that are at the core of the Ark of Inquiry project. The web-based materials aim at helping teachers to *adopt* the Ark of Inquiry. Second, teachers are invited to take part in teacher training sessions to learn to use the Ark of Inquiry in their classrooms. The teacher training comprises (1) inquiry learning in general, (2) the Ark of Inquiry pedagogy (Framework of Inquiry Proficiency, Evaluation System and Award System), and (3) adaptation of the Ark of Inquiry activities (pedagogical scenarios). The teacher training aims at helping teachers successfully *implement* the Ark of Inquiry in their own classrooms. In the long run, the Ark of Inquiry project seeks to equip teachers with the necessary skills and knowledge in order for them to become designers of classrooms in which young people can practice inquiry learning and scientific reasoning as well as become responsible citizens who are able to take into account the relevance, consequences and ethical issues related to scientific discovery and innovations for themselves, others and society. More information can be found on the project website http://www.arkofinquiry.eu/.

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References

Bybee, R., Taylor, J. A., Gardner, A., van Scotter, P., Carlson, J., Westbrook, A., et al. (2006). *The BSCS 5E Instructional Model: Origins and Effectiveness*. Colorado Springs, CO: BSCS.

Colburn, A. (2000). An Inquiry Primer. *Science Scope, March*, 42-44.

de Jong, T., & Njoo, M. (1992). Learning and Instruction with Computer Simulations: Learning Processes Involved. In E. de Corte, M. Linn, H. Mandl & L. Verschaffel (Eds.), *Computer-based learning environments and problem solving* (pp.411-429). Berlin, Germany: Springer-Verlag.

Kim, Y., & Lim, J. (2013). Gendered Socialization with an Embodied Agent: Creating a Social and Affable Mathematics Learning Environment for Middle-grade Females. *Journal of Educational Psychology*, *105*(4), 1164-1174.

Pedaste, M., Mäeots, M., Leijen, Ä., & Sarapuu, S. (2012). Improving Students' Inquiry Skills through Reflection and Self-regulation Scaffolds. Technology, *Instruction, Cognition and Learning*, *9*, 81-95.

Pedaste, M., Mäeots, M., Siiman L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of Inquiry-based Learning: Definitions and the Inquiry Cycle. *Educational Research Review*, *14*, 47-61.

Pedaste, M., & Sarapuu, T. (2014). Design Principles for Support in Developing Students' Transformative Inquiry Skills in Web-based Learning Environments. *Interactive Learning Environments, 22*, 309-325.

Robertson, S. I. (2001). *Problem solving*. Hove: Psychology Press.

Robinson, W. S. (2009). Ecological Correlations and the Behavior of Individuals. *International Journal of Epidemiology, 38*(2), 337-341.

Ryan, R. M., & Deci, E.L. (2000). Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology, 25*, 54-67.

Von Schomberg, R. (Ed.). (2011.) *Towards Responsible Research and Innovation in the Information and Communication Technologies and Security Technologies Fields. Luxembourg: Publications Office of the European Union*. Retrieved August 24, 2015, from http://ec.europa.eu/research/science-society/document_library/pdf_06/mep-rapport-2011_en.pdf.

Stahl, B. C. (2013). Responsible Research and Innovation: The Role of Privacy in an Emerging Framework. *Science & Public Policy (SPP)*, *40*(6), 708-716. doi:10.1093/scipol/sct067

Stahl, B. C., McBride, N., Wakunuma, K., & Flick, C. (2014). The Empathic Care Robot: A Prototype of Responsible Research and Innovation. *Technological Forecasting & Social Change*, 8474-85. doi:10.1016/j.techfore.2013.08.001

Stilgoe, J., Owen, R., & Macnaghten, P. (2013). Developing a Framework for Responsible Innovation. *Research Policy*, *42*, 1568-1580. doi:10.1016/j.respol.2013.05.008

Wenger, E. (1998). *Communities of Practice: Learning, Meaning and Identity*. Cambridge: Cambridge University Press.

White, B. Y., & Frederiksen, J. R. (2000). Metacognitive Facilitation: An Approach to Making Scientific Inquiry Accessible to All. In J. Minstrell & E. van Zee (Eds.), *Inquiring into Inquiry, Learning and Teaching in Science* (pp. 331–370). Washington, DC.: American Association for the Advancement of Science.

Wilhelm, P., & Beishuizen, J. J. (2003). Content Effects in Self-directed Inductive Learning. *Learning and Instruction*, *13*, 381-402. doi:10.1016/S0959-4752(02)00013-0.

Zeidner, M., Boekaerts, M., & Pintrich, P.R. (2000). Self-regulation: Directions and Challenges for Future Research. In M. Boekaerts, P.R. Pintrich & M. Zeidner (Eds.), *Handbook of self-regulation* (pp.749-768). New York/London: Academic Press.