ASSESSING PROBLEM SOLVING COMPETENCE THROUGH INQUIRY-BASED TEACHING IN SCHOOL SCIENCE EDUCATION

Panagiotis Zervas[1], Sofoklis Sotiriou[2], Rüdiger Tiemann[3] and Demetrios G. Sampson[4]
[1]*Department of Digital Systems, University of Piraeus, 150, Androutsou Str., GR 185 32 Piraeus, Greece*
[2]*Ellinogermaniki Agogi, Dimitriou Panagea Str. GR 153 51 Pallini Attikis, Athens, Greece*
[3]*Department of Chemistry, Chemistry Education, Humboldt-Universität zu Berlin,*
Brook-Taylor-Str. 2, 12489 Berlin, Germany
[4]*School of Education, Curtin University, Kent Street, Bentley WA 6102, Australia*

ABSTRACT

Nowadays, there is a consensus that inquiry-based learning contributes to developing students' scientific literacy in schools. Inquiry-based teaching strategies are promoted for the development (among others) of the cognitive processes that cultivate problem solving (PS) competence. The build up of PS competence is a central objective for most compulsory education (K-12) curricula and a critical competence for both professional career readiness and effective citizenship. A widely accepted framework for assessing individual students' PS competence at large scale is PISA 2012 Problem Solving Framework (PSF). Nevertheless, PISA 2012 PS competence assessment is primarily summative (one-off assessment) and disconnected from the daily school science teaching practice. Within this context, the aim of this paper is to address this issue by proposing a framework for incorporating assessment tasks of PISA 2012 PSF to the various phases of an inquiry teaching model. This framework sets the ground for supporting domain specific assessment of students' problem solving competence during day-to-day school science teaching practice.

KEYWORDS

School education, science education, inquiry-based learning, PISA 2012 problem solving framework

1. INTRODUCTION

Science education plays a critical role in societies' competitiveness and economic future (Lewis & Kelly, 2014). Developing scientific literacy in compulsory school education requires preparing students in four main strands, namely (Alberts, 2009): (a) to know, use, and interpret scientific explanations of the natural world, (b) to generate and evaluate scientific evidence and explanations, (c) to understand the nature and development of scientific knowledge and (d) to participate productively in scientific practices and discourse.

Within the rich literature on this topic, there are many studies that recognize the advantage of authentic learning practices such as inquiry-based learning towards developing students' scientific literacy (Crawford et al., 2014; Gormally et al., 2009). More specifically, inquiry is the process in which students are engaged in scientifically oriented questions, perform active experiments, formulate explanations from empirical evidence, evaluate their explanations in light of alternative explanations, and communicate and justify their proposed explanations (National Research Council, 2000). To this end, inquiry-based teaching models are recognized as appropriate teaching strategies to support deep understanding of subject domain knowledge and prepare students to apply this knowledge in novel real-life situations (OECD, 2013). Thus, to be able to measure (among others) the effectiveness of inquiry-based learning, assessment of students' problem-solving competences is needed (Scherer & Tiemann, 2014).

A widely accepted framework for assessing individual students' problem solving competence is the PISA 2012 Problem Solving Framework (PSF), which has been developed by the Organization for Economic Co-operation and Development (OECD) to address the need for cross-nationally comparable evidence for student performance on problem solving (OECD, 2013). However, PISA 2012 problem solving competence assessment is primarily summative (one-off assessment) and disconnected from the daily school science teaching practice. Within this context, the aim of this paper is to address this issue by proposing a framework for incorporating assessment tasks of PISA 2012 PSF to the various phases of an inquiry teaching model. This framework set the ground for supporting domain specific assessment of students' problem solving competence during day-to-day school science teaching practice.

2. INQUIRY BASED LEARNING

Inquiry-based learning is often organized into inquiry phases that together form an inquiry cycle. However, different variations on what is called the inquiry cycle can be found throughout the literature (Pedaste et al., 2015). A widely used inquiry learning model is the 5E Model, which lists five inquiry phases, namely Engagement, Exploration, Explanation, Elaboration, and Evaluation (Bybee et al., 2006). In our work, we have adapted the 5E Model by considering also the inquiry cycle proposed by Bell et al. (2010). More specifically, according to Bell et al. (2010), the following inquiry phases have been adopted:

- **Orienting and Asking Questions:** This phase involves the presentation of the problem to be engaged with and aims to provoke curiosity.
- **Hypothesis Generation and Design:** This phase involves the formulation of initial hypotheses from the students based on their own reason and current understanding of the matter at hand.
- **Planning and Investigation:** This phase involves the collection, analysis and organization of the research/experimentation processes and the related tools/resources that will facilitate these. This can be discovered by the students or provided by the teacher.
- **Analysis and Interpretation:** During this phase, the learners engage in experimentations following the processes outlined in Phase 3 and utilizing the tools/resources selected in the same phase.
- **Conclusion and Evaluation:** This phase includes reflective analysis of the learners initial hypotheses based on the newly acquired knowledge and experience. Moreover, it aims to assist learners in gaining a more holistic view of the scenario problem.

3. ORGANISING PROBLEM SOLVING ACTIVITIES IN INQUIRY CYCLE PHASES

The Programme for International Student Assessment (PISA) has proposed a widely accepted framework for assessing individual students' problem solving competence at large scale, namely PISA 2012 Problem Solving Framework (PSF). The PISA 2012 PSF defines four (4) different steps for solving a complex problem namely (OECD, 2013, p. 126), as follows:

- **Exploring and understanding the problem:** this step includes (a) exploring the problem situation (observing, interacting, searching for information and limitations) and (b) understanding the given information and the information discovered while interacting with the problem situation.
- **Representing and formulating the problem:** this step includes (a) selecting relevant information, mentally organizing and integrating with relevant prior knowledge and (b) shifting between representations or formulating hypotheses by identifying the relevant factors.
- **Planning and executing the strategy for solving the problem:** this step includes: (a) clarifying the overall goal and setting sub-goals and (b) devising a plan or strategy to reach the goal state. After that, in the executing phase, the plan is carried out.
- **Monitoring and reflecting the solution:** this final step includes: (a) monitoring the progress towards reaching the goal at each stage including checking intermediate and final results, detecting unexpected events, and (b) reflecting on solutions from different perspectives and critically evaluating assumptions and alternative solutions.

The range of problem solving assessment tasks included in the PISA 2012 PSF allows for describing six levels of problem solving proficiency that can be grouped into three main categories, namely (OECD, 2014, p. 56-60):

- **High Performers (Level 5 and Level 6):** students at this category can: (a) develop complete, coherent mental models of different situations and (b) find an answer through target exploration and a methodical execution of multi-step plans.

- **Moderate Performers (Level 3 and Level 4**): students at this category can: (a) control moderately complex devices, but not always efficiently and (b) handle multiple conditions or inter-related features by controlling different variables.
- **Low Performers (Level 1 and Level 2):** students at this category can: (a) answer if a single, specific constrain has to be taken into account and (b) partially describe the behavior of a simple, everyday topic.

In order to be able to assess students' problem solving competence (following the PISA 2012 PSF) within the context of inquiry-based learning, it is essential to incorporate appropriate assessment tasks in the various phases of the inquiry cycle (as specified in section 2). Table 1 presents our proposed framework, which comprises: (a) the mapping between the problem solving steps and the inquiry cycle phases (specified in section 2) and (b) proposed guidelines for developing assessment tasks towards assessing each of the problem solving steps at the different phases of the inquiry cycle.

Table 1. Mapping between PISA 2012 problem solving steps and Inquiry Cycle Phases

Inquiry Phases	PISA 2012 Problem Solving Steps	Guidelines for Preparing Assessment Tasks
Orienting and Asking Questions	Exploring and Understanding the Problem	1. Deal with the representation of the problem 2. Deal with relevant information to understand the problem 3. Deal with different levels of understanding of subject domain knowledge
Hypothesis Generation and Design	Representing and Formulating the Problem	1. Deal with the exploration of correlations and dependencies 2. Deal with a precise description of the focused problem
Planning and Investigation	Planning and Executing the Strategy for Solving the Problem	1. Deal with the correct strategies of experimentation 2. Deal with strategies of variable control 3. Deal with strategies for data analysis
Analysis and Interpretation	Monitoring and Reflecting the Solution	1. Deal with application or transfer of problem tasks 2. Deal with possible sources of experimental errors 3. Deal with enhancement of experimental setting
Conclusion and Evaluation	-	-

4. CONCLUSIONS

In this paper, we demonstrated a framework for incorporating and contextualizing within the various phases of an inquiry cycle, the PISA 2012 problem solving framework for assessing individual student's problem solving competence. However, the use of this framework calls for taking up some future challenges, which could be summarized as follows

- **Methods for assessing PS competence:** different methods can be used ranging from traditional paper and pencil assessments (multiple choice, constructed or open response items) to student logs, artefacts and portfolios (Hickey et al., 2012). Additionally, in contrast to the PS competence that is supposed to be subject-independent, the assessment tasks should be designed, so as to be subject-domain oriented and embedded in the respective discipline (Scherer & Tiemann, 2014).
- **Support science teachers for implementing effective assessment of their students' PS competences:** This needs to be addressed by appropriate teacher professional development activities, which should not be constrained only to the process of selecting suitable assessment methods and developing effective assessment tasks, but they must also address science teachers' teaching attitudes that can be a significant barrier to the implementation of the assessment of their students' PS competences (Timmers et al., 2013; Webb et al., 2013)

It is worth mentioning that the aforementioned framework is currently being exploited by a major European Initiative, namely the Inspiring Science Education (ISE) Project (http://www.inspiring-science-education.org/), which aims to assess students' PS competence at large scale, namely by involving a large number of schools, teachers and students from 13 EU member states. More specifically, the ISE project aims to develop a set of digital tools that can support the authoring and delivery of technology-enhanced science lessons which incorporate students' problem solving competence assessment (with appropriately designed multiple choice items) as part of the different inquiry phases during daily science teaching practice.

ACKNOWLEDGMENTS

The work presented in this chapter has been partly supported by the Inspiring Science Project that is funded by the European Commission's CIP-ICT Policy Support Programme (Project Number: 325123). This document does not represent the opinion of the European Commission, and the European Commission is not responsible for any use that might be made of its content.

REFERENCES

Alberts, B., 2009. Redefining science education. *Science*, Vol. 323, No. 5913, p. 437.

Bybee, R. W. et al., 2006. *The BSCS 5E instructional model: Origins and effectiveness*. Colorado Springs, CO, BSCS, Colorado, USA.

Bell, T., et al.. 2010. Collaborative inquiry learning: Models, tools, and challenges. *International Journal of Science Education*, Vol. 32, No. 3, pp. 349-377.

Crawford, B. A., et al., 2014. Learning to Teach Science as Inquiry: Developing an Evidence-Based Framework for Effective Teacher Professional Development. In C. Bruguière, A. Tiberghien, P. Clément (Eds.), *Topics and Trends in Current Science Education*, (pp. 193-211). Springer: Netherlands.

Gormally, C., et al., 2009. Effects of inquiry-based learning on students' science literacy skills and confidence. *International Journal for the Scholarship of Teaching and Learning*, Vol. 3, No. 2, p. 16.

Hickey, D. T., et al. 2012. Assessment as learning: En-hancing discourse, understanding, and achievement in innovative science curricula. *Journal of Research in Science Teaching*, Vol. 49, No. 10, pp. 1240–1270

Lewis, J. L., & Kelly, P. J., 2014. *Science and technology education and future human needs*. Elsevier.

National Research Council, 2000. *Inquiry and the national science education standards. A guide for teaching and learning.* Washington DC: National Academy Press

Organisation for Economic Co-operation and Development (OECD), 2014. *PISA 2012 Results: Creative Problem Solving: Students' Skills in Tackling Real-Life Problems (Volume V).* PISA, OECD Publishing

Organisation for Economic Co-operation and Development (OECD), 2013. *PISA 2012 assessment and analytical framework: mathematics, reading, science, problem solving and financial literacy*.

Pedaste, M., et al., 2015. Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, Vol. 14, pp. 47-61.

Scherer, R., & Tiemann, R, 2014. Measuring students´progressions in scientific problem solving: a psychometric approach. *Procedia – Social and Behavioral Sciences,* Vol. 112, pp. 87-96.

Timmers, C. F., et al. 2013. Motivational beliefs, student effort, and feedback behaviour in computer-based formative assessment. *Computers & Education,*Vol. 60, No. 1, pp. 25-31

Webb, M., et al., 2013. Challenges for information technology supporting educational assessment. Journal of Computer Assisted Learning, Vol. 29, No. 5, pp. 1365-2729.