Assessment in Science Education

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Abstract. An analyses study focusing on scientific reasoning literacy was conducted to strengthen the stressing on assessment in science by combining the important of the nature of science and assessment as references, higher order thinking and scientific skills in assessing science learning as well. Having background in developing science process skills test items, inquiry in its many form, scientific and STEM literacy, it is believed that inquiry based learning should first be implemented among science educators and science learners before STEM education can successfully be developed among science teachers, prospective teachers, and students at all levels. After studying thoroughly a number of science researchers through their works, a model of scientific reasoning was proposed, and also simple rubrics and some examples of the test items were introduced in this article. As it is only the beginning, further studies will still be needed in the future with the involvement of prospective science teachers who have interests in assessment, either on authentic assessment or in test items development. In balance usage of alternative assessment rubrics, as well as valid and reliable test items (standard) will be needed in accelerating STEM education in Indonesia.

1. Introduction
Entering year 2020, career of science graduates will be focused in competencies needed in the 21st century such as critical thinking and creativity as ways of knowing, communication and collaboration as ways of working [1], which is most familiar as Four C competencies. Stressing too much on science content mastery will be time and energy consuming. It is mostly expected to develop higher order thinking skills in the form of valid test items as well as combination of self- and peer-assessment on inquiry based instruction and meaningful student learning experience.

Inquiry is actually the nature of science itself. Inquiry based instruction has four to five forms: as a method, as an approach, as a learning model, as tools to develop personality, and as competency to be develop and assessed [2]. Meanwhile levels of inquiry had been introduced as discovery learning, interactive demonstration, inquiry lesson, inquiry laboratory, real world application, and hypothetical explanation [3]. Each level of inquiry has pedagogical purpose and intellectual scientific skills. Therefore the "competencies" developed in inquiry based learning is very useful to be used as the scientific skills as what are mostly expected in 2013 curriculum in Indonesia, In spite of its scientific approach through all subject matter, scientific skill and reasoning skill is very important for science in junior high school as well as for science major (Biology, Chemistry, Physics) in senior high school.

There is closed relationship between science instruction and science assessment. The nature of assessment is needed to be developed in the nature of science as inquiry, active assessment for active science. Assessment can be differentiated into ‘assessment of learning’, ‘assessment for learning’, and ‘assessment as learning’ based on the goal, whereas based on its function it can be differentiated into...
formative assessment and summative assessment [4]. Formative assessment directs the learners to learn further, while summative assessment tends to direct the learner to compete each other.

Science process skills had been studied before, whether as learning or as assessment [5, 6, 7, 8, 9, 10]. Their studies showed that there are some characteristics in their science process skill assessment, especially in test items, among others are as follows. They used the concepts as context, measured each science process indicators specifically, and put some information before asking something in their stem of test items to be interpreted by the respondents. Therefore the characteristics of test items on science process skills are quite different from test items for measuring concept mastery, as they should be able to differentiate those who cannot answer the test because they do not have science process skills from those who do not understand the concepts to be mastered.

Inquiry have been defined in its many form [2]. Inquiry had also been differentiated based on its level of approaches [3]. There are many more definition of inquiry in science instruction, as it can be found in National Science Education Standard [11] and in Science Inquiry [12]. Unfortunately assessment for inquiry learning is still not well defined, and also the studies about inquiry assessment during the instruction. The leveling on science inquiry will be a good start for preparing assessment for scientific inquiry, because they are spectrum of intellectual sophistication from low to high and range of locus of control from teacher to student.

This article is trying to define how to assess inquiry, propose a model, and introduce simple rubrics as assessment for learning and some types of test items to assess the scientific reasoning skills (intellectual scientific skills) as assessment of learning. The results are still in progress. Actually the title of this article is proposed as “A concept model about scientific reasoning literacy: Case study on science learning assessment”.

2. Method
a) Meta-analyses study from S2 Science students who have been teaching science in Junior high school for more than 6 years (2015, 2016, 2017) who try to implement performance assessment on science learning, especially in STEM based learning.

b) Observation and discussion with participants during biology teachers workshop in determining the cognitive process dimension and during biology learning in lab school (March-May 2017) who still have difficulties in planning & constructing instructional objectives as well as test items on cognitive process dimension, especially in determining from the simple one (C1) to more and most complex (C6). They still confused on the key words for each level of taxonomy (C1-C6).

c) Observing science teacher’s activities and response during inquiry based science teaching and learning in workshop (May 3rd.- May 13th. 2017) who still have difficulties in responding scientific reasoning [13], and tend to have dual perspective scoring rubric. The rubric was prepared from the discussion among all workshop participants.

d) Studying documents from Wenning’s works by his permission.

| Inquiry Levels      | Intellectual skills                                                                 | # |
|---------------------|--------------------------------------------------------------------------------------|---|
| Discovery Learning  | Rudimentary intellectual skills                                                      | 7 skills |
|                     | • Classifying; Conceptualizing; Concluding                                           | inductive reasoning |
|                     | • Contextualizing; Ordering; Generalizing                                           | inductive reasoning |
|                     | • Problematizing                                                                   | inductive reasoning |
| Interactive         | Basic intellectual skills                                                           | 4 skills |
| Demonstration       | o Estimating; Predicting, Using conditional thinking                                | deductive reasoning |
| Inquiry Lesson      | Intermediate intellectual skills                                                    | 5 skills |
|                     | • Applying information                                                              | inductive reasoning |
|                     | • Describing relationships; using combinatorial Reasoning; using correlational reasoning; | deductive reasoning |
|                     | • Making simple sense of quantitative data                                          | inductive reasoning |
|                     | o Defining precisely a problem to be studied;                                       | inductive reasoning |
|                     | o Defining precisely the system to be studied                                        | deductive reasoning |
| Inquiry Labs        | Integrated intellectual skills                                                      | 4 skills |
|                     | o Interpreting quantifiable data to establish laws using logic                       | deductive reasoning |
|                     | o Designing& conducting controlled scientific                                       | deductive reasoning |
Inquiry Levels | Intellectual skills | # |
--- | --- | --- |
Real World Application | Culminating intellectual skills | investigations; • Using causal reasoning to distinguish coincidence from cause and effect • Using causal reasoning to distinguish correlation from cause and effect • Using data & math in the solution of real-world problems • Summarizing for the purpose of logically justifying a conclusion on the basis of empirical evidence. • Using proportional reasoning to make prediction • Determining if an answer to a problem or question is reasonable including size and/or units | inductive reasoning 6 skills deductive reasoning |
Hypothetical Explanation | Advanced intellectual skills* | o Generating predictions through the process of deduction; Thinking deliberately o Generating & evaluating analogies o Thinking analogically; Thinking reflectively o Thinking to assimilate concepts | deductive reasoning 6 skills |

*not yet developed [14]

Data analysis were carried out qualitatively through triangulation and assertion of questions. Some results of observation, documentation and framework on science researcher were used as tools in this study. These analysis resulted in a model on scientific reasoning plus rubrics for inquiry based teacher competencies and student’s characteristic in science learning through inquiry as a draft.

3. Result and Discussion
a) The result of meta-analyses study shows that high school student still have difficulties in scientific processes conducted by S2 science students especially in reasoning or intellectual ability in the last three years (2014, 2015, 2016). Nevertheless when they learned science through well planned STEM based science instruction, they did improve their scientific processes as well as their engineering design practice [14, 15]. In STEM education there are three partite as integration (cross cutting concept, core ideas of discipline, and engineering design practice. Students learn through inquiry based learning and integrated with project based learning. When the process was planned systematically through D-D-O (define-develop-optimize) in the engineering design practice in STEM education [16] the students will be able to improve their scientific ability as well as their concept mastery according to Cognitive Bloom’s taxonomy [17]. Therefore to improve student ability in scientific process-intellectual (=reasoning) the teacher can start from science or scientific literacy through inquiry based learning, and then gradually develop their ability or literacy through gradual type inquiry based learning. Later the students can improve their technology and engineering literacy.

| Table 2. Scientific Practices and Cross Cutting Concepts of the NGSS Framework [18] |
| --- | --- | --- |
| Asking questions | Defining problems | Patterns |
| Developing models | Using models | Scale, proportion, quantity |
| Planning investigation | Carrying out investigation | Systems and Systems Models |
| Using mathematics | Using computational thinking | Stability and Change |
| Constructing explanation | Designing solution | Energy and Matter |
| Engaging argument from evidence | Engaging argument from evidence | Cause and Effect |
| Obtaining & communicating information | Evaluating and communicating information | Structure and Function |
| | | Connection to engineering, technology & application of science |
The cross-cutting concepts enable teachers and students to focus the science teaching learning process toward the important things of the connection interdisciplinary concept. Therefore stressing on concept mastery will not be needed any longer, instead its application which is called as literacy (applying concepts meaningfully).

b) Based on observation resulting from science teacher’s activities and their response during inquiry based science learning in workshop held from May 3rd to May 13th 2017, it was found that science teachers and science trainers (“Widyaiswara”) still are not used to scientific reasoning type test items [19]. There was a tendency that they even have lack experience in preparing such type of questions in constructing scientific processes and higher order thinking skills. Type of questions used by science teachers will determine the quality of test items and imaginative context whether lower order or higher order thinking skills [20].

c) Based on the interactive discussion results during the workshop on inquiry based science learning held on May 3rd to May 13th 2017, it was found that the participants could think merely from teacher’s perspective, not from student perspective. So to direct them first they have to think from their own perspectives, then coincident they think from student’s perspective. Later based on this result, task and rubrics were developed and then were used to monitor the improvement of science teachers and their students in inquiry based learning. This instrument was prepared as dual perspective scoring rubric. The rubric was prepared through discussion, and judged through monitoring and evaluation process during trial-out implementation by model teachers at partner schools.

d) Based on the thorough study on Wenning’s documentation about his works and his students work by his permission (May 6th., 2017), it was found that some efforts had been done by other scientists or science educators about assessment on test item construction. Most of their works related to certain framework. Related to scientific processes and reasoning ability, some frameworks are used as references in developing sets of test items, such as scientific literacy in PISA [21], Nature of Science Literacy Test [22], Scientific Inquiry Literacy Test [23]; cognitive process according to Cognitive Bloom’s Taxonomy [17], and Classroom Test of Formal Reasoning [24]-[25]. Scientific Practices and Intellectual Skills was created as framework for Science Reasoning Literacy Test (SciReLiT) based on Levels of Inquiry Model of Science Teaching by Carl J. Wenning [13]. Some example of test items were studied to get the main idea of framework dealing with how to assess scientific or intellectual skill as the results of inquiry based science learning.

Refer to the 21st. century skills, and considering the whole of the study resulted in from the triangular analysis, at last it is decided to introduce “A concept model about scientific reasoning literacy: Case study on science learning assessment”. The model proposed has characteristics as follows. Firstly, it assesses science process skills focusing on intellectual or reasoning aspects in the form of paper and pencil test set, and in the form of performance assessment (task and rubrics) of test items instruments and using alternative assessment in balance at the same time. All these show that the model uses the nature of science, the nature of science literacy, and the nature of assessment.

By definition, 21st. century learning tasks can be open-ended, involve unbounded sets of information, and may involve on-going redefinitions of the goal of task. It is important that students develop skills to establish and adapt goals according to available information, seek out relevant and valid information for the task, and continually monitor their own progress. The teacher’s role is to set highly motivating tasks with achievable goals and to provide sufficient structure and scaffolding based on a thorough understanding of the students’ interests and needs. The students also sets goals and targets for their own learning, and move forward with a clear understanding of the usefulness and application of the new skills and understanding they are developing [26].

Another approach that fits well with the teaching of 21st. century skills is tailored and differentiated instruction. It was stated that teachers in differentiated classroom draw upon strategies such as a small-group instruction, materials presented at a variety of reading levels, personalized rubrics, learning contracts, a variety of product and task options with common learning goals, and independent studies. Small-group instruction may be particularly helpful in targeting learning tasks, allowing students to shape their own learning goals and to seek out and select materials and information of relevance to the
task. The task of teacher is to provide the most effective structure through the establishment of smaller
groups based on similar abilities or to provide opportunities for peer mentoring.

A developmental approach to assessment and learning is directed to the aim of the approach to
using assessment for teaching 21st century skills is to move a student’s learning forward along a path
or progression of increasingly complex knowledge and capabilities [26]. The focus is on recognition of
a student’s readiness to learn and the process of building upon the current stage of learning. By
contrast, a deficit approach to assessment and teaching focuses on discovering, the things that a student
cannot do, and teaching is then designed to address those deficits.

Variation for students at different stages on cognitive or social skill progression can be
differentiated into four stages id est. stage A to D [26]. In Levels of Inquiry, instead of simultaneous
development of scientific reasoning, it was propose to plan learning sequences. Based on the learning
sequences, certain skills which are still missing can be directed and then be assessed [3]. So both
approaches enable the students to improve their learning by the help of more knowledgeable Others
(MKO), and Zone of proximal development (ZPD) through scaffolding [27]. The concept of the zone
of proximal development (ZPD), which can be thought of as an ideal space in which people can learn
most effectively. People learn effectively within their ZPD because they have enough prior knowledge
to scaffold their learning of more complex skills or information, but not so much as to lead
disengagement because they are being taught concepts or material that are too simple.

4. Conclusion
A combination of paper and pencil test focusing on multiple choice test item with reason, and
performance or alternative assessment is proposed as a model of scientific reasoning/intellectual
literacy as science learning outcome of high school students. The alterative assessment is in the form
of task and rubrics that reflects 21st century skills which consider as part of four competencies (4Cs).
The test on scientific reasoning skills literacy and rubrics for assessing the essence of each level of
inquiry can be developed gradually with the involvement of graduate students through their
investigation in their thesis writing. In the perspective of the nature of science, the nature of science
literacy and the nature of assessment, it is focused to empower the assessment for learning and as
learning to complete the assessment of learning.

Acknowledgments
The writer would like to extend their deepest gratitude to Carl J Wenning from Illinois State
University for the permission to overview Hanson’s thesis for the workshop in general and especially
for this study with the support of World Bank and PPPPTK IPA.

References
[1] Binkley M, Erstad O., Herman J., & Raizen S., Ripley, M., Miller-Ricci, M., & Rumble, M.
2012. “Defining twenty-first century skills”. In Griffin, P., McGaw, B., & Care, E. (Eds.)
Assessment and Teaching of 21st Century Skills. New York: Springer Science-Business
Media B.V.DOI 10.1007/978-94-007-2324-5.
[2] Rustaman, N.Y. 2007. “Basic Scientific Inquiry in Science Education and Its Assessment”.
Paper presented as Keynote speech in First International Seminar in Science Education.
Held by Science Education Study Program, Graduate School, Indonesia University of
Education.
[3] Wenning C J 2010 Levels of Inquiry: Using inquiry spectrum learning sequences to teach
science J. of Physics Teacher Education Online 5 11-20
[4] Popham W J 2011 Classroom Assessment: What Teachers Need to Know Fourth edition
(Boston: Allyn and Bacon)
[5] Bell J, Black P, Johnson S, Murphy P, Quatter A and Russell T 1989 Assessment Performance
Unit: Science at age 15 (London: Her Majesty’s Stationery Office)
[6] Schilling M, Hargneaves L, Harlen W, and Russell T 1990 Written Tasks (London: Paul
Chapman Publishing Ltd.)
[7] Harlen W, Macro C., SchilingM, Malvern D, Reed K 1990 *Progress in Primary Science: Workshop Materials for Teacher Education* (London: Routledge)

[8] Russell T, and Harlen W 1990 *Assessing Science in the Primary Classroom: Practical Tasks* (London: Paul Chapman Publishing Ltd.)

[9] Rustaman N Y, Firman H. and Rustaman A. 1992. *Pengembangan dan Validasi Butir Soal Keterampilan Proses Sains sebagai Persiapan Wajib Belajar Pendidikan Dasar Sembilan Tahun*. Laporan Penelitian yang didanai DP2M Dirjen Dikti.

[10] Rezba R J, Sprague C and Fiel R L 2006 *Learning and Assessing Science Process Skills* (Dubuque, Iowa 52002: Kendall/Hunt Publishing Company)

[11] The National Research Council 1996 “Assessment in Science Education” In *National Science Education Standard* (Washington D.C.: National Academy Press) pp. 75-101

[12] National Research Council. 2000. Inquiry.

[13] Hanson S T, and Wenning C J. (2017). Framework for Science Reasoning Literacy Test (SciReLiT) version 8, February 9.

[14] Afianti E, Rustaman, N and Suwarma, IR 2017 Performance Assessment Implementation in STEM-Based Learning to Investigate Students’ Creativity on the Cell Topic. Article draft

[15] Septiani A, and Rustaman N Y, 2016. Implementation of performance assessment in STEM education to detect science process skills. [online] 2016 [cited 2017 May 2] Available from: URL: http://publikastilmiiah.ums.ac.id

[16] Bybee R W 2013 *The case for STEM education: Challenges and opportunity* (Arlington, VI: National Science Teachers Association (NSTA) Press)

[17] Anderson LW and Krathwohl D R Eds. 2001 *A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom Taxonomy of Educational Objectives* (New York: Addison-Wiley Longman)

[18] National Research Council 2013 *Next Generation Science Standards Framework* (Washington DC: National Academies Press)

[19] Hanson S T. 2016. *The Assessment of Scientific Reasoning Skills of High School Students: A Standardized Assessment Instrument*. Thesis, Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science, School of Teaching and Learning, Illinois State University

[20] Lazear D 2004 *Higher-Order Thinking: The Multiple Intelligences Way* (Chicago: Zephyr)

[21] OECD 2007 *PISA 2006 Science Competencies for Tomorrow World: Volume I Analysis* (OECD Publishing)

[22] Wenning C J 2006 Assessing nature-of-science literacy as one component of scientific literacy *J. of Physics Teacher education Online* 3 (4) 3-14

[23] Wenning C J 2007 Assessing inquiry skills as a component of scientific literacy *J. of Physics Teacher Education Online* 4 (2) 21-24

[24] Lawson A E, Adi H and Karplus R 1979 Development of correlational reasoning in secondary schools: do biology courses make a difference? *The American Biology Teacher* 41 420-425

[25] Lawson A E 2005 What Is the Role of Induction and Deduction in Reasoning and Scientific Inquiry? *Journal of Research in Science Teaching* 42 (6)716-740

[26] Woods K., Mountain R., and Griffin P. 2015. Linking developmental progressions to teaching. In Griffin, P., McGaw, B., & Care E. (Eds.). *Assessment and Teaching of 21st Century Skills: Methods and Approach. Educational Assessment in an Information Age: Series Editor* (New York: Springer Science-Business Media Dordrecht)

[27] Vygotsky L S 1978 *Mind and society: The development of higher mental processes* (Cambridge, MA: Harvard University Press)