**IMPACT OF REPRESENTATIONAL APPROACH ON THE STUDENTS UNDERSTANDING OF MECHANICS CONCEPTS, REASONING ABILITY, AND GENERIC SCIENCE SKILLS**

**Sutopo**

FMIPA Universitas Negeri Malang

Email: [sutopo.fisika@um.ac.id](mailto:sutopo.fisika@um.ac.id)

***The aim of this research was to improve students’ understanding of mechanics concepts, ability to reason, and generic science skills (GSS) simultaneously using a representational approach in which the students collaboratively solve open-ended, multifaceted problems using coherent multiple representations through activities that include arguing, writing, drawing, modeling, and graphing; while the lecturer functions as an expert guide for the students. A mixed-methods, embedded experimental design had been implemented. Subject consisted of 24 undergraduate students of Physics Education Program, State University of Malang, enrolling the Selected Topics of School Physics course. Data analyses were based on the students’ pretest and posttest using an integrated test adapted from Mechanics Baseline Test (Hestenes & Wells, 1992), field notes, and questionnaire. This research concluded (1) the students’ competence on mechanics mostly (50%) jumped from under-competent level to mastery level; (2) the students’ reasoning ability was improved with upper-medium N-gain (0.62); and (3) the students’ GSS, including self-consistent thinking, causality thinking, performing logical inference, sense of scale, and using symbolic language, were improved with high N-gain for the first three skills (0.79, 0.68, and 0.65, respectively), upper-medium N-gain (0.56) for the fourth, and lower-medium N-gain (0.45) for the last.***

***Keywords:*** *representational approach, mechanics concepts, reasoning ability, generic science skills*

**1. INTRODUCTION**

This research is guided by a vision that the graduates of physics education program should be able to prepare their future students for becoming scientifically literate citizens, which able to use scientific processes in making personal decision and to participate in discussion of scientific issues that affect society (NRC, 1996, 2012). It implies that they need able to construct scientific explanation, i.e. a reason that links logically data or evidences and scientific idea (concepts, principles, theories, laws) in making a claim. They also should have robust understanding of physics content as a compelling scientific explanation requires deep understanding of science knowledge underlying the problems being discussed. Deep understanding of physics content is also regarded as a prerequisite of good physics teacher (Etkina, 2010). Teachers with more content knowledge are more likely to successfully explain the concepts, if they use best teaching practices that fully support

student‟s content construction and development of abstract concepts in science (NSTA, 2011). Teachers also need able to communicate and clarify scientific ideas effectively using multiple representations to exchange and clarify meanings (Ainsworth, Prain, & Tytler, 2011). In addition, they need to understand the processes to establish new knowledge and determine the validity of claims (Eylon & Bagno, 2006). Therefore, student-teachers physics need ample opportunities to cultivate their ability to reason while struggling to grasp deep understanding of physics content throughout physics courses that they take during pre- service program.

Constructing scientific explanations in which students support their claims with appropriate evidence and reason is an important element of scientific inquiry (NRC,

1996, 2012). Engaging in explanation can also help students develop deeper

understanding of science content. Dolan and

Grady (2010) noted that students‟ activity to

represent data in multiple ways including tables and graphs while thoughtfully consider the meaning of their representation as the highest level of reasoning in inquiry. Accordingly, Waldrip et al. (2010) conceptualized the science learning as the process and outcomes whereby students come to understand how to interpret and construct scientific explanations using the representational conventions of the subject.

Recent researchers in science education argue that to learn science effectively students

need to understand the different representations of science concepts and

processes, be able to translate a representation into one another, and understand their

coordinated use in representing scientific knowledge (Hubber et al., 2010; Prain et al.,

2009). The ability to use multiple

representations is considered key to learning physics (Kohl et al., 2007). Students with higher representation ability have higher chance to solve complex problems successfully (Malone, 2008). Rosengrant et al. (2009) found evidence that students who frequently use multiple representations are successful in FCI (force concept inventory), MBT (mechanics baseline test), and CSEM (conceptual survey of electrostatics and magnetism) tests. Ainsworth (2008) argued that multiple representations play three major functions in learning. First, they play *complementary roles* as each representation may differ in the information it expresses or in the processes it supports. Second, they play *constrain interpretations* role of other representation. The use of multiple representations is to help students in understanding a difficult representation (because of its complexity or abstractness) using easier representation (because of its familiarity or concreteness). Third, they play *to construct deeper understanding*. The use of multiple representations is to help students to grasp deeper understanding through integrating information from more than one representation.

During the last decade, science education researchers in Indonesia have paid attention to

develop students‟ generic science skills (GSS)

through leaning science (Ramlawati et al.,

2011, Sudarmin, 2011, Wijaya & Ramalis,

2012). GSS is thinking skills and actions closely connected to science as a process and

based on the science knowledge (Brotosiswoyo, 2000; Liliasari et al., 2011). GSS includes (1) performing direct and indirect observation, (2) developing sense of scale or magnitude of physical quantity, (3) using symbolic language, (4) self- consistent thinking, (5) employing logical inference, (6) causality thinking, (7) mathematics modeling, and (8) developing concept (Brotosiswoyo,

2000). It is believed that GSS plays as a base to build high order thinking and is transferable to many other situations. Therefore, the prospective physics teachers need to develop the skill as it is useful not only for their further content knowledge growth, but also for teaching the skill to their future students. However, the effort to equip students GSS is still a challenge. Liliasari et al. (2011) argued that it is quite difficult to develop GSS for prospective science teachers. Those reports suggest the necessity of an alternative teaching approach that is different from the more traditionally implemented.

Throughout this research, a representa- tional approach in learning physics has been

developed and implemented for students of

prospective physics teachers. The approach is attributed as representational since the main students‟ learning activity is to construct multiple representations and use their representations to grasp deep understanding of physics ideas underlying the problem being discussed. Students‟ learning activities were designed by considering various works on science education research, especially in the area of the use of multiple representations on learning physics, or science in general. These include the works exploring the value of expert-developed representations as well as student-generated representations in learning physics. The later includes the assertion of Waldrip et al. (2010) that unless students can represent their understanding in various modes of representation, their knowledge is unlikely to be sufficiently robust or durable, as well as the assertion of Ainsworth et al. (2011) that engaging students in constructing their own representation will deepen their conceptual understanding and be regarded as the central role of developing expertise. The assertion of Halloun and Hestenes (1985) about the ineffectiveness of conventional- passive student instructions in learning mechanics, the finding of Hake‟s (1998)

survey about the effectiveness of interactive- engagement methods, the Heuvelen‟s (2001) assertion about the importance of multiple exposures for learning new or difficult concepts and skills over an extended time and in variety of contexts, and the work of Ogilvie (2009) and Mullis et al. (2009) about the value of open-ended, multifaceted problem have been utilized as important inputs.

The characteristics of this approach are as the followings. (1) The lecturer prepares a particular problem that includes key concepts and skills for which students are intended to learn. (2) Through intensive group discussion, students collaboratively struggle to make meaning about physics concepts being discussed using their own representations. They do this meaning making not only **from** representation but also **with** representation. (3) In this process, the lecturer functions as an expert guide to student‟s emerging accounts of the topic. There are some possibilities of lecturer‟s intervention. (a) Whenever the students have a high degree of certainty about their representations, the lecturer prompts them to justify their reasoning through clarification. (b) Whenever the students are uncertain about their represented claim, or face deadlock in discussion, the lecturer provides them the necessary scaffolds to prompt further reasoning. (c) Whenever most groups do not have the necessary skill or knowledge to construct more appropriate representation, or have no idea or questions to critique the appropriateness of their representation, lecturer provides the necessary scaffold(s) through class discussion or dialogue. (4) After group discussion, lecturer facilitates whole class discussion to consolidate student understanding. In addition to the above characteristics, (5) Lecturer needs to pay much attention to any student‟s misunderstanding, misconception, confusion, or ambiguity, and provides strategy(s) that enable students to redress those deficiencies.

This research focuses on the impact of

the approach on students‟ learning of fundamental concepts in mechanics, based on the following considerations. (1) Mechanics concepts are the foundation of other branches of physics and mostly relate to physical phenomena in everyday experiences. Therefore, the mastery of mechanics concepts is an important goal of physics education

(Indonesian MONE regulation No 22 year

2006 about Content Standard; NRC, 2012), and becomes important targets for educational

interventions in school (Singh & Schunn,

2009). (2) Much of the physics education researchers during the last three decades (e.g. Clement, 1982; Hake, 1998; Halloun & Hestenes, 1985; Rosenblatt & Heckler, 2011; Sayre et al., 2012, Shaffer & McDermott,

2005) showed that the concepts of Newtonian mechanics are considerable difficult to be learned and the teaching of Newtonian mechanics is quite challenging. (3) There is available well known instrument to assess students‟ mastery of mechanics concepts, i.e. Mechanics Baseline Test (MBT) developed by Hestenes and Wells (1992), that has been broadly used to examine the effectiveness of many reformed courses in mechanics (e.g. Hake, 1998). Therefore, there is possibility to measure the effectiveness of the present teaching approach using international standard and compare its effectiveness with the previous works, though documentarily.

Accordingly, this research is intended to address the following research questions: to what extent does the representational approach improve students‟ conceptual understanding of mechanics concepts, reasoning ability, and generics science skills?

**2. METHODS**

To address the proposed research questions, a mixed-methods embedded experiment, one group pretest posttest design (Creswell and Clark, 2007) has been implemented to address the proposed research questions. Subject consisted of 24 under- graduate students of physics education program, State University of Malang, enrolling the STSP course provided for prospective physics teacher for international school. They had undertaken Introductory Physics and Mechanics courses presented in the previous semesters. Mechanics topics being discussed included linear motion, parabolic motion, circular motion, simple harmonics oscillator, and physics behind roller coaster. Posttest was administered at the end of semester, instead of in a week just after the mechanics topics had been finished. In addition, mechanics topics discussed throughout the lessons did not cover all concepts being tested. The lecturer also

avoided to „teaching the test‟ throughout the

lessons.

The main instrument was an integrated test adapted from Mechanics Baseline Test (MBT) developed by Hestenes and Wells (1992). The original MBT instrument consists of 26 multiple choice items designed to assess student‟s conceptual understanding of mechanics “that cannot be grasped without formal knowledge about mechanics” and “require algebraic manipulation or more than one-step reasoning” (Hestenes & Wells: 159-

161). According to Hake (1998: 65), “MB test requires conceptual understanding in addition to some mathematical skill and critical thinking”. Based on the pilot study involving

52 students, this final instrument consisted of

22 multiple choices items with the following characteristics. Coefficient of correlation

between item score with total score varied from r = 0.32 (p < 0.05) to r = 0.62 (p < 0.01),

the item‟s discrimination index varied from

0.29 (moderate) to 0.86 (very high), and index of easiness varied from 0.12 (difficult) to 0.63

(moderate). The Cronbach‟s Alpha coefficient

of this instrument was 0.81, indicating very good reliability (Everitt & Skrondal, 2010).

The instrument was used to assess

students‟ conceptual understanding of mechanics and reasoning ability simul-

taneously. For this purpose, the students not

only chose one alternative that best represents their response, but also wrote explanations to justify their answer. The student‟s conceptual

understanding of mechanics and GSS were measured based on their multiple choices response, while their reasoning ability was assessed based on their open explanations.

There are five GSS components that can be measured using this MBT instrument. They are: sense of scale (SS), using symbolic language (SL), self-consistent thinking (SC), performing logical inference (LI), and causality thinking (CA). The students‟ reasoning ability was addressed by two aspects, i.e. technical and conceptual validity. Technical aspect refers to the fulfillment of Toulmin‟s reasoning components. The corresponding rubric (Table 1) was adapted from the work of Furtak et al. (2010). Conceptual validity refers to the correctness and appropriateness of the physics concepts, theories, principles, or laws employed in reasoning. The corresponding rubric (Table 2) was constructed by combining the “validity outcome space” and “conceptual sophisticat- ion outcome space” of reasoning proficiencies proposed by Brown et al. (2010: 155-156).

For checking coding reliability, 25% of reasoning units were coded by primary rater (researcher) and one secondary independent rater. There were 528 reasoning units (i.e. 24 students  22 items) for each data set. The percentage agreement of the two raters was

78% for the technical aspect and 87% for the

conceptual validity aspect; yielding Cohen‟s

kappa of 0.71 and 0.80 respectively.

Table 1. Rubric to code technical aspect of student‟s reasoning quality

Category Score/ level Definition

Inductive/ deductive rule-based reasoning

Evidence- based reasoning

4 The rationale consists of a comprehensive data analyses supported by principle, theory, law, or definition that are relevant to the data and problem being solved. The scientific correctness of the theory, law, etc. used in this reason is not important.

3 The rationale has considered an amount of data (including implicit data) and applied a relevant data analyses, but not enough to solve the problem correctly.

Data-based reasoning 2 The rationale relies on a limited data or the surface feature of the problem.

No reasoning 1 The rationale, if any, is merely restatement of the claim (response) or not clearly relates to the problem nor clear in meaning.

Unidentified 0 Student‟s answer sheet is blank

Adapted from Furtak, Hardy, Beinbrech, Shavelson, and Shemwell (2010)

Table 2. Rubric to code the conceptual validity aspect of student‟s reasoning

Category Score/ Level Definition

Fully valid 3 Claim is correct and follows from the relevant and correct backup

Partially valid 2  Claim is correct but the backup is not fully appropriate (incomplete or partially irrelevant), or

 Claim is incorrect since it follows from inappropriate backup

Invalid 1  Claim is incorrect since it follows a fully incorrect backup or does not logically follow from backup, or

 Claim is correct but fully follows incorrect backup

Unidentified 0  No rationale, or the rational is tautological

3. **RESULTS AND DISCUSSION**

**a. The Improvement of The Students’**

**Understanding of Mechanics Concepts**

Students‟ scores on pretest and posttest as well as their normalized gains are summarized in Figure 1. The mean of the posttest was greater than that of pretest (Figure 1, right). A paired samples *t*-test yielded *t* = 14.12, *p* = 0.00 (2-tailed), suggesting that the representational approach implemented in this research improved students‟ understanding of mechanics concepts. The improvement was strong as its d-effect size was 2.5, in the category of “much larger than typical” (Morgan, Leech, Gloeckner, & Barrett, 2004, p.91), and

Hake‟s average N-gain was 0.63 (upper- medium category). Students with lower (less than the average) pretest score tended to get lower gain, and vice versa (Figure 1, left). It suggests that most students took proportional advantage from the teaching-learning process to improve their understanding of mechanics concepts. The interpretation of d-effect size is based on the criteria proposed by Morgan et al. (2004), whereas the interpretation of N- gain is based on Hake‟s refined categorization

as follow: low if 〈 〉 < 0.25, lower-medium if

〈 〉 , upper-medium if

〈 〉 , and high if 〈 〉

It is useful to examine the improvement

of students‟ understanding in term of their

competence in mechanics. Hestenes and

Wells (1992) argued that a score of 60% on

the MBT is the threshold for problem-solving competence. Below this threshold, student‟s grasp of Newtonian concepts is too limited for effective problem solving. A score of 80% is the threshold for mastery of basic Newtonian concepts. They believed that when it is approached, other goals of physics instruction would be much easier to attain. In this research, the levels of students‟ mechanics competence are categorized as follows: “under competent” if MBT score <

60.0%, “competent in problem solving” if

60.0% ≤ MBT score < 80.0%, and “mastery in basic Newtonian mechanics” if

MBT score ≥ 80.0%. Figure 1 (right) shows

that the approach successfully assisted most students to jump from “under competent” level to “mastery” level. Moreover, there was no student in mastery level before instruction, whereas 50% of students were in this level after instruction.

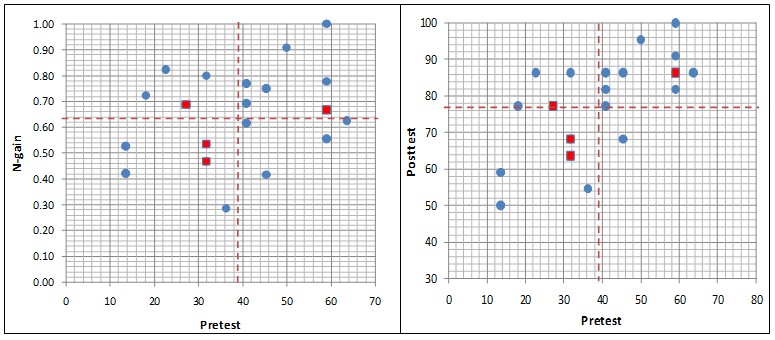


Figure 1. Scatter plots of N-gain versus pretest (left) and posttest versus pretest (right). The mean of pretest (dashed vertical line), posttest (horizontal line in figure right), and N-gain (horizontal line in figure left) was 39.2 (SD =15.3), 77.5 (SD = 13.0), and 0.64 (SD = 0.17) respectively. The bullets represent single data, while the squares represent doublet data.

The low result of student‟s mechanics competence before instruction was not expected as they had previous taken one semester courses in Mechanics and Introductory Physics. This phenomenon was similar to our previous study (Sutopo, Liliasari, Waldrip, & Rusdiana, 2011) involving 35 students who had taken Introductory Physics plus 24 students who had taken both Introductory Physics and Mechanics. Average score was 33% (SD =

17%) with maximum score of 68%. Those

findings indicate that students‟ deficient understanding of Newtonian mechanics persists beyond the school physics and could not be adequately addressed throughout the two university courses.

To understand the effectiveness of this approach, it is useful to elaborate the

qualitative findings drawn from students‟

open explanation on pre- and post-test as well

as from phenomena encountered throughout the lessons. Based on the students‟ responses on pretest, there were evidences that most students hold some misconceptions about acceleration, including: (1) acceleration is always in the same direction as the motion or velocity; (2) the magnitude of acceleration is proportional to the magnitude of velocity; (3) acceleration is in the direction to which the object tends to move; (4) in any frictionless track, the object‟s acceleration is zero; and (5) if there is no friction and other external applied force, the acceleration of an object moving under influence of gravity is equal to the gravitational acceleration **g**, even though there exists such „passive force‟ as normal force or tension in a rope. Students also misunderstood the relationship between acceleration and force as stated in Newton‟s second law of motion, **F** = *m***a**. They

considered this equation as causality rather than covariance relationship.

Based on the phenomena encountered throughout the first few lessons, there were

evidences that the students hold some prior deficient understandings. They: (1) tended to define velocity as „distance divided by time‟,

instead of „displacement divided by time elapsed‟ or „the rate of change in position

with time‟; (2) could not apply the operational

definition of velocity as well as acceleration to

analyze motion diagram; (3) could not define

the change of position (**x**) even though they had been able to make vector operations such as (**A** + **B**) and (**A****B**) where **A** and **B** are vectors unconnected to any physical quantity; and, (4) believed that acceleration was always in the same direction as the velocity, the minus sign on acceleration meant deceleration, and acceleration should be inferred from resultant force; but not in

reverse. It can be believed that those deficient

5. S3: *“Yah, It means that the velocity is*

*decreasing ...”*

6. S1: *“Wait! Why we always start from t zero? ... how if we calculate the velocity at every interval of 2 seconds, from t = 0 to 2 s, then from t =2s to 4 s, etc?”*

7. S2: *“Could be, let’s try. ... For the first interval, v = 36/2 = 18 m/s. For second interval, v = (63**36)/2 = 13.5 m/s, ... for the third ... v = 8.5 m/s ... Yah, it’s decreasing too”.*

8. S1: *“Yah, but the result is different from the previous. Look, v3 is very different! Our previous result was 13.3 but now is 8.5.*

*...”*

9. S3: *“So how?”* [Discussion faced deadlock]

10. L: *“What are you talking about? You are*

*really talking about speed rather than velocity. Moreover, you are talking about average speed, instead of instantaneous speed. Your task is to describe how velocity changes with time. It means, you need to talk about instantaneous velocity. For example, what’s the velocity at t =*

*2s, at t = 3 s, and so on.”*

11. S1: *“I have an idea. We’ve had equation of*

*2*

understandings have caused the low student

*position x (t) =* *1.2t*

*+ 20.4t. To get*

scores on the pretest.

The students worked in small groups where they developed solutions as a group and developed a common response as to why their solution was adequate. During this process, students made and justified a claim as to the solution, through student-student and a group-teacher dialogue. The following transcript shows an example of a dialogue in a group when the group attempted to describe how velocity changes with time. This dialog happened upon the group had described how position changes with time. The students discussed the problem (line 1-9) and faced a deadlock (line 9). The lecturer‟s prompt (line

10) inspired the students to propose a new idea (line 11). Afterward, the lecturer required

students to construct another representation

(line 14).

1. S1: *“Now we should describe how the position changes with time”.*

2. S2: *“From diagram we can know the distance traveled for some interval of time. For example at t = 2s, the distance is 36 m then v = 18 m/s. At t = 4 s ...”*

3. S1: *“is 63 m then v = 15.75 m/s.”*

4. S2: *“At t = 6 s, the distance is 80 m then v =*

*13.33 m/s ....”*

*velocity, we need to simply take its*

*derivative v = dx/dt ... the result is v(t) =*

*2.4 t + 20.4.”*

12. S2: “*Yah, this equation describes how the*

*velocity changes with time.”*

13. S3: *“We can also use this equation to define the velocity at any instant of time. For example, at t = 0, v = 20.4 m/s; at t = 2, v*

*=* *4.8 + 20.4 = 16.4 m/s, etc.”*

14. L: *“Good job! So, you’ve gotten a*

*mathematical representation of the velocity. Now, please describe it using a diagram, that is, draw the velocity vector at any instant of time”*

Throughout the lessons, there were evidences that most students had improved and developed better understanding in the areas outlined above. It can be argued that the representational approach implemented in this study could remediate students‟ miscon- ceptions, or common sense, about Newtonian mechanics concepts, even though the lessons were not designed initially to assess and remediate those misconceptions.

Based on the students‟ responses to the

questionnaire, there were evidences that students have taken considerable benefits from their learning. All groups asserted that their understanding of the concepts being discussed improved. By conceptual

understanding it included strengthening or deepening the existing understanding, remediating misconceptions, constructing new concept, and identifying key concepts involved in the physics problems. It also (1) improved their problem solving skill, including the confidence to use their own ideas in solving problems, instead of relying on the textbook; (2) improved their skill and confidence in communication, discussion, and collaboration; (3) improved ability to verify the validity of an opinion by checking its consistency with other representations; (4) ability to describe physics phenomena scientifically and evidently; and (5) improved skill in using computer software to make graphs, calculations, and data analysis.

“*By trying to describe our idea using a variety of representations, we can deeply understand the concepts being discussed ... able to describe physics phenomena scientifically (using the relevant physics ideas appropriately) and convincingly (using a variety of coherent representations). .... Now we are dare to not rely on the textbooks in solving physics problem, instead we need to deepen our understanding of the essential concepts and use them consistently.*

*... Learning physics becomes enjoyment as we can find out the key concepts involved in a problem and successfully solve the problem; we engage in the finding of the key concepts throughout the lessons. .... We improve our skill of using computer software such as Microsoft Excel to make graphs, calculations, and data analysis. We improve our skill of discussion and collaboration in a group*.”

The effectiveness of this approach confirms some previous research about representations. Some researchers argue that to learn science effectively, students need to understand the different representations of science concepts and processes, be able to translate a representation into one another, and understand their coordinated use in representing scientific knowledge (Hubber, Tytler, & Haslam, 2010; Prain, Tytler, & Peterson, 2009). Similarly, Carolan, Prain, and Waldrip (2008) found that the teaching science in which the teacher focuses on students‟ thinking and reasoning enables students to grasp deep understanding of science concepts. This present research also confirms the „construct deeper understanding‟ function of multiple representations in learning science (Ainsworth, 2008). However,

in this present research, students did not just respond to the representations provided by lecturer or available in textbooks. Instead, students constructed their own representations and used them to make meaningful understanding of the concept being represented. According to Ainsworth, Prain, and Tytler (2011), engaging students in constructing their own representation will deepen students‟ conceptual understanding. The finding of this research also confirms the claim of Rosengrant, Heuvelen, and Etkina (2009) that students who frequently use representations will be successful on the MBT.

**b. The Improvement of The Students’**

**Reasoning Ability**

The students‟ reasoning scores on pretest and posttest as well as their N-gains are summarized in Table 3. A paired samples t- test yielded t = 14.96, p = 0.00 (two-tailed) for the technical aspect and t = 14.49, p =

0.00 (two-tailed) for the conceptual validity aspect; suggesting that the means difference

between pair of data sets are statistically

significant. The d-effect size on technical and conceptual validity aspect was 2.58 and 2.51, respectively. These effect sizes are in the category of much larger than typical. The Hake‟s average N-gain was 0.62 (upper- medium category) for both technical and conceptual validity aspect. It can be argued that the representational approach implemented in this research has high effectiveness to improve students‟ reasoning ability.

The change of the reasoning quality level performed by students was also analyzed.

Students‟ reasons were coded according to the

level of reasoning quality using rubrics presented in Table 1 and 2. The resulting data

are summarized in Table 4 and 5. The Chi-

square test resulted in 2 = 74.98 (p = 0.00) and 2 = 77.12 (p = 0.00) for the technical and conceptual validity aspects, respectively. This test suggested that the posttest distribution was significantly different from the pretest distribution for both technical and conceptual validity aspects. For the technical aspect (Table 4), the proportion of the highest level (Lev-4) changed from about 19% in pretest to about 61% in posttest, whereas the

lowest two levels decreased from about 44% to about 12%. For the conceptual validity aspect (Table 5), the proportion of the highest level (Lev-3) changed from about 17% in

pretest to about 63% in posttest, whereas the lowest two levels decreased from about 65% to about 21%.

**Table 3. Descriptive statistics of students’ reasoning scores**

**Technical Aspect**

**Conceptual Validity Aspect**

**Statistics (Scale 0****4) (Scale 0****3)**

**Pre Post N-gain Pre Post N-gain**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Minimum | 1.2 | 2.3 |  | 0.26 |  | 0.7 |  | 1.5 |  | 0.24 |
| Maximum | 3.0 | 4.0 |  | 0.98 |  | 2.1 |  | 3.0 |  | 1.00 |
| Mean (SD) | 1.99(0.44) | 3.23(0.51) |  | 0.63(0.21) |  | 1.32(0.41) |  | 2.37(0.43) |  | 0.64(0.20) |
| Skewness | 0.11 | 0.29 |  | 0.15 |  | 0.10 |  | 0.43 |  | 0.01 |

**Table 4. Posttest-pretest crosstabulation of reasoning levels for the technical aspect**

PRETEST

POSTTEST Total Pretest

Total Posttest

\*) Relative to the total of reasoning units (528)

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Lev-0 | Lev-1 | Lev-2 | Lev-3 | Lev-4 |  | Count | %\*) |
| Lev-0 | 2 | 2 | 4 | 3 | 9 |  | 20 | 3.8 |
| Lev-1 | 7 | 37 | 19 | 24 | 126 |  | 213 | 40.3 |
| Lev-2 | 1 | 11 | 31 | 25 | 77 |  | 145 | 27.5 |
| Lev-3 | 0 | 2 | 11 | 10 | 27 |  | 50 | 9.5 |
| Lev-4 | 0 | 0 | 3 | 13 | 84 |  | 100 | 18.9 |
| Count | 10 | 52 | 68 | 75 | 323 |  | 528 | 100 |
| %\*) | 1.9 | 9.8 | 12.9 | 14.2 | 61.2 |  | 100 |  |

**Table 5. Posttest-pretest crosstabulation of reasoning levels for the conceptual validity aspect**

PRETEST

POSTTEST Total Pretest

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Lev-0 | Lev-1 | Lev-2 | Lev-3 |  | Count | %\*) |
| Lev-0 | 14 | 23 | 12 | 56 |  | 105 | 19.9 |
| Lev-1 | 12 | 47 | 39 | 142 |  | 240 | 45.5 |
| Lev-2 | 1 | 8 | 33 | 52 |  | 94 | 17.8 |

Total

Posttest

Lev-3 0 4 5 80 89 16.9

Count 27 82 89 330 528 100

%\*) 5.1 15.5 16.9 62.5 100

\*) Relative to the total of reasoning units (528)

The improvement of students‟ ability to reason was as expected according to anecdotal comments from the lecturer and students‟ reflection to their learning. In this respect, the lecturer argued that,

“*The approach encouraged students to think critically and reason logically throughout the*

*lessons. Through constructing representations to*

*solve problems of discussion, students learned to check the consistence of their representations with the available data and the relevant theories,*

*concepts, and principles underlying the problems, as well as to check the coherence of their tentative representation with the previous representation(s) they had already constructed. Through group and whole class discussions, students attempted to make the best argumentation for defending their idea”.*

and students claimed that,

“*By trying to describe our idea using a variety of representations, we were able to describe physics phenomena scientifically (using the relevant*

*physics ideas appropriately) and convincingly*

*(using a variety of coherent representations)”.*

It can be argued that the approach has provided students with ample opportunities to develop their ability to construct claims that were backed up by appropriate theory and comprehensive data analysis. As the result, students could develop both reasoning and representational skills concurrently as they tried to explain and justify their represented understanding or idea.

**c. The Improvement of The Students’**

**Generic Science Skills**

Student‟s GSS scores on pretest and posttest are summarized in Table 6. It appears that some data sets (i.e. sense of scale, symbolic language, and causality) are approximately normal, whereas the other two data sets are not normal as they are quite skewed. Therefore, to examine the statistical significance of the difference between posttest

and pretest, a paired-samples t-test has been employed to the former group and non- parametric Wilcoxon Signed Ranks Test (Leech et al., 2005) for the later group. Those tests show that the differences between pair of data sets are statistically significant at p =

0.000. It means that the representational approach implemented in this study could

improve the students‟ generic science skills.

To examine the strength of the improvement, the corresponding d-effect size (Ellis, 2010; Morgan et al., 2004) and average N-gain (Hake, 1998) have been calculated for each component. The results are summarized in Table 7. From this table, it appears that the effect size is in “much larger than typical” category for all GSS. The average N-gain is in “high” category for the three skills (self- consistence, causality, and logical inference) and in “medium” category for the other two skills.

Table 6. Descriptive statistics of students‟ pretest, posttest, and N-gain scores for each GSS

component

**Statistics**

**GSS**

**Component**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **First Second Third** | | | | | | | **Mean** |  |
| Pretest | 0 | 75 | 6.25 | 25 | 50 | 28.1 | 21.3 | 0.21 |
| Posttest | 25 | 100 | 50 | 75 | 94 | 67.7 | 26.0 | -0.36 |

**Min Max**

**Quartile**

**Mean SD**

**Skewness**

N-Gain 0.00 1.00 0.27 0.59 0.94 0.56 0.35 -0.28

**Logical**

**Inference**

**Self**

**Consistence**

**Symbolic**

**Language**

**Sense of**

**Scale**

**Causality**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pretest |  | 0 |  | 80 |  | 20 |  | 40 |  | 60 |  | 39.2 |  | 23.2 |  | -0.28 |
| Posttest |  | 40 |  | 100 |  | 40 |  | 70 |  | 80 |  | 68.3 |  | 22.8 |  | 0.03 |
| N-Gain |  | 0.00 |  | 1.00 |  | 0.06 |  | 0.45 |  | 0.73 |  | 0.45 |  | 0.37 |  | 0.28 |
| Pretest |  | 0 |  | 75 |  | 0 |  | 0 |  | 50 |  | 17.7 |  | 25.0 |  | 0.94 |
| Posttest |  | 25 |  | 100 |  | 75 |  | 87.5 |  | 100 |  | 82.3 |  | 21.5 |  | -1.08 |
| N-Gain |  | 0.00 |  | 1.00 |  | 0.75 |  | 0.88 |  | 1.00 |  | 0.79 |  | 0.27 |  | -1.46 |
| Pretest |  | 0 |  | 75 |  | 25 |  | 50 |  | 75 |  | 47.9 |  | 25.4 |  | -0.36 |
| Posttest |  | 25 |  | 100 |  | 75 |  | 100 |  | 100 |  | 82.3 |  | 22.7 |  | -1.03 |
| N-Gain |  | 0.00 |  | 1.00 |  | 0.33 |  | 1.00 |  | 1.00 |  | 0.65 |  | 0.42 |  | -0.55 |
| Pretest |  | 20 |  | 80 |  | 40 |  | 60 |  | 80 |  | 58.3 |  | 18.6 |  | -0.54 |
| Posttest |  | 60 |  | 100 |  | 80 |  | 90 |  | 100 |  | 86.7 |  | 15.2 |  | -0.67 |
| N-Gain |  | 0.00 |  | 1.00 |  | 0.50 |  | 0.84 |  | 1.00 |  | 0.68 |  | 0.38 |  | -0.81 |

To examine the strength of the improvement, the corresponding d-effect size (Ellis, 2010; Morgan et al., 2004) and average N-gain (Hake, 1998) have been calculated for each component. The results are summarized in Table 7. From this table, it appears that the

effect size is in “much larger than typical” category for all GSS. The average N-gain is in “high” category for the three skills (self- consistence, causality, and logical inference) and in “medium” category for the other two skills.

Table 7. Effect size and average N-gain for each GSS component

GSS Component a) d-Effect Size Average N-Gain Value Category b) Value Category

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Self-Consistence (SC) | 2.88 | Very large | 0.79 | High |
| Causality (CA) | 1.68 | Very large | 0.68 | High |
| Logical Inference (LI) | 1.43 | Very large | 0.65 | High |
| Sense of Scale (SS) | 1.67 | Very large | 0.56 | Upper-medium |
| Symbolic Language (SL) | 1.27 | Very large | 0.45 | Lower-medium |

a): Ordered by N-gain b): Very large means “much larger than typical”

It is useful to examine whether gain scores among GSS components are statistically different. For this purpose, a Friedman test had been implemented as some data sets are not normally distributed. The result is 15.42, p =

0.004. This means that, in overall, those N-

gains are significantly different at = 0.01. To determine which differences between mean ranks are significant, and thus the likely source of the significant Friedman test, the follow up analysis using Wilcoxon test has been employed. The results show that only three of the ten possible pairs are significantly different. These are the pairs of SC-SS, SC- SL, and CA-SL. Moreover, N-gain of LI is not significantly different from that of any other components. Based on this statistical analysis, it is clear that N-gain of self-consistence and causality components are significantly higher than that of sense of scale and symbolic language components. This claim is in high agreement with the value of N-gains shown in Table 6; the average N-gain of SC and CA are in high category, whereas of SS and SL are in medium category.

Efforts to promote generic science skills

(GSS) through science courses have been critical issue in Indonesia during the last

decade, after Brotosiswoyo (2000) argued the

importance for university students to grasp these skills through university physics courses. It is now broadly accepted that these skills need to be developed through science classrooms in all levels of schooling in

Indonesia as they are needed for better learning science, transferable to many other situations, and as a base for developing higher order thinking (Liliasari, 2010). However, Liliasari et al. (2011) argued that it is difficult to develop GSS on students of prospective science teachers. This claim confirmed the findings of previous researches, especially on the area of physics education research, such as Abdurrahman (2010), Saprudin (2010), and Sutarno (2010). Therefore, it is useful to compare the findings of the present research to those of previous researches.

As previously described, the repre- sentational approach implemented in this study significantly improved the students‟ GSS. More specifically, the improvement on self- consistent and causality thinking skills was so high that the corresponding N-gains were in the category of high gain (0.79 for self- consistence and 0.68 for causality). The corresponding results of the previous researches are as follows. (1) Abdurrahman (2010), by implementing multiple- representation in teaching quantum physic, improved students causality and self- consistent thinking skills with N-gain of about

0.56 and 0.53 (in average) respectively. (2) Saprudin (2010) and Sutarno (2010), by

implementing multimedia interactive,

improved causality component with N-gain of

0.37 and 0.58 respectively. They did not assess the improvement of self-consistent thinking skill. In addition, the N-gains of other GSS components intervened by those researches

were in the category of medium. This comparison indicates that the teaching approach implemented in this research can be considered to be more effective than that implemented in the previous researches, especially in improving self-consistent and causality thinking skills. However, it is useful to review briefly the difference between teaching approach implemented in this present research and that implemented in the previous researches.

Basically, those previous researchers implemented a teaching approach that is

similar to that implemented in this present

research, but with different strategy. Those researchers used multiple representations as a tool for teaching in which students learn (or making meaning) **from** representations provided by lecturer. In another word, they used expert-generated representation strategy. Such teaching strategy is basically based on Mayer‟s theory of multimedia learning (Mayer, 2005, Mayer & Moreno, 2010) and Ainsworth‟s (2008) assertion about the values of multiple representations in learning science. On the other hand, the teaching approach implemented in this present study was basically student-generated representation strategy. Students struggle to construct meaning of science idea, express their idea using their own representation, and negotiate their understanding within and among other students as well as with the lecturer. In another word, students make meaning of science idea with representation. This comparison suggests that strategy of making meaning **with** representations is likely more effective than strategy of making meaning **from** representations to improve students‟ GSS.

The high improvement on self-consistent thinking, causality thinking, and logical inference is as expected as lecturer intensively facilitated the students to develop those skills throughout the lessons. On the problems of kinematics, for instance, the lecturer always asked the students to develop data, construct graph based on their data, draw the most appropriate mathematical model for their graph, and draw conclusion about the nature of the motion. When the students had drawn a conclusion about the acceleration of the motion, the lecture always prompted the students by posing questions such as: “Is there any net force acting on the ball? If your answer is not, how do you draw the

conclusion? Otherwise, if your answer is yes, explain your claim and describe the force that you notice using a range of media including words, diagram, etc.” To address those requirements, students not only need to think self-consistently, but also to employ causality thinking and logical inference as well. It means that students had ample opportunities to cultivate the thinking skills over an extended time and in various contexts. According to Heuvelen (2001), the teaching method that provides students such multiple exposures will lead the students to acquire better learning outcomes.

The result of the present research is also in line with the work of Moore and Rubbo (2012). They found that to develop reasoning ability such as hypothetico-deductive reasoning, students need opportunities to construct good “if ... and ... then ....” statements as much times as possible. The teaching approach that merely focuses on content acquisition does not improve students reasoning. As stated in advance, the teaching approach implemented in this present study also provided the students with ample opportunities to develop their reasoning skills including self-consistence, logical inference, and causality thinking.

It is useful to explain why N-gain of using symbolic language is the lowest one (see Table 6). In fact, this approach has paid much attention on the development of this students‟ skill. Activities to construct pictorial repre- sentation, such as vector representation of velocity and acceleration as well as free force diagram, closely relate to this goal. Such activities almost happened throughout the lessons. However, the N-gain of this skill was the lowest one. This situation can be explained as follows. Some items assessing this skill deal with physics concepts that were not mentioned throughout the lessons, such as the change in momentum due to the collision and the impulse exerted by one object to another during collision. Some students failed to respond the items correctly. It implies that the nature of generic science skill is content- dependent. It is consistent with the assertion of Brotosiswoyo (2000) and Liliasari et al. (2011).

4. **CONCLUSION**

Based on the results and discussion presented in the previous section, this research reaches the following conclusions. The instructional approach implemented in this research, in which the students collaboratively solve open-ended, multifaceted problems using coherent multiple representations through activities that include arguing, writing, drawing, modeling, and graphing; while the lecturer functions as an expert guide for the students can improve students‟ conceptual understanding of mechanics, reasoning ability, and generic science skills, simultaneusly.

1. Students‟ conceptual understanding of mechanics was improved with very high effect size (2.5) and upper-medium N-gain (0.63); their competence on mechanics mostly (50%) jumped from “under- competent” level to “mastery” level.

2. Students‟ reasoning ability was improved with upper-medium N-gain (0.62) and very high effect size on both technical (2.58) and conceptual validity (2.51) aspect. Their reasoning quality mostly shifted from lower levels to the highest level.

3. Students‟ generic science skills that include

(1) self-consistent thinking, (2) causality thinking, (3) logical inference, (4) sense of

scale, and (5) using symbolic language were

improved with very high effect size for all skills (1.27 to 2.88) and with N-gain that is in high category for the first three skills (0.79, 0.68, 0.65), upper-medium category (0.56) for the fourth, and lower-medium category (0.45) category for the last.

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**REFERENCES**

Abdurrahman. 2010. *The role of quantum physics multiple representations to enhance concept mastery, generic science skills, and critical thinking disposition for Pre-service physics teacher students*. Ph. D dissertation, Indonesia University of Education: unpublished.

Ainsworth, S. 2008. The educational value of multiple representations when learning complex scientific concepts. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp.191-208). New York: Springer.

Ainsworth, S., Prain, V., & Tytler, R. 2011.

Drawing to learn in science. *Science,* 333:

1096-1097.

Brotosiswoyo, B.S. 2000. *Hakikat pembelajaran fisika di perguruan tinggi*.

Jakarta: Proyek Pengembangan Universitas

Terbuka, Direktorat Jendral Perguruan

Tinggi, Depdiknas RI.

Brown, N.J.S. et al. (2010). “A framework for analyzing scientific reasoning in

assessments”. *Educational Assessment*. 15

(3), 142174.

Carolan, J., Prain,V., and Waldrip, B. (2008). “Using representation for teaching and learning in Science”. *Teaching Science*. 54, (1), 1823.

Clement, J. (1982). “Students‟ preconceptions

in introductory mechanics”. *American*

*Journal of Physics*. 50, (1), 6670.

Creswell, J.W. and Clark, V.L.P. (2007).

*Designing and conducting mixed methods research.* Thousand Oaks, California: Sage Publications.

Dolan, E. and Grady, J. (2010). “Recognizing

students‟ scientiﬁc reasoning: A tool for categorizing complexity of reasoning

during teaching by inquiry”. *Journal of*

*Science Teacher Education.* 21, 31–55

Ellis, P.D. 2010. *The essential guide to effect sizes: Statistical power, meta-analysis, and*

*the interpretation of research results*. New

York: Cambridge University Press.

Etkina, E. (2010). “Pedagogical content knowledge and preparation of high school physics teachers”. *Physical Review Special Topic- Physics Education Research.* 6,

020110.

Everitt, B.S. & Skrondal, A. 2010. *The Cambridge dictionary of statistics 4th edition*. New York: Cambridge University Press.

Eylon, B. and Bagno, E. (2006). “Research- design model for professional development of teachers: designing lessons with physics education research”. *Physical Review Special Topic- Physics Education Research.* 2, 020106.

Furtak, E. M., Hardy, I., Beinbrech, C., Shavelson, R. J. & Shemwell, J. T. (2010). A framework for analyzing evidence-based reasoning in science classroom discourse. *Educational Assessment*. 15, (3), 175196.

Hake, R.R. 1998. Interactive-engagement versus traditional methods: A six-thousand-

student survey of mechanics test data for

introductory physics courses. *American*

*Journal of Physics*, 66 (1): 64-74.

Halloun, I.A. & Hestenes, D. 1985. Common

Sense Concepts about Motion. *American*

*Journal of Physics*, 53 (11): 1056-1065. Hardy, I., Kloetzer, B., Moeller, K., & Sodian,

B. 2010. The analysis of classroom

discourse: Elementary school science curricula advancing reasoning with

evidence. *Educational Assessment*, 15 (3):

197-221.

Hestenes, D. & Wells, M. 1992. A Mechanics

Baseline Test. *The Physics Teacher,* 30:

159-166.

Heuvelen, A.V. 2001. Millikan lecture 1999: The workplace, student minds, and physics

learning system. *American Journal of*

*Physics*, 69 (11): 1139-1138.

Hubber, P., Tytler, R., & Haslam, F. 2010.

Teaching and learning about force with a representational focus: Pedagogy and

teacher change. *Research in Science*

*Education,* 40: 5–28.

Kohl, P.B., Rosengrant, D., & Finkelstein, N.D. 2007. Strongly and weakly directed

approaches to teaching multiple representation use in physics. *Phys. Rev. ST*

*Phys. Educ. Res*., 3, 010108.

Leech, N.L., Barrett, K.C., & Morgan, G.A.

2005. *SPSS for intermediate statistics: Use and interpretation* (second edition). New

Jersey: Lawrence Erlbaum Associates Inc.

Liliasari, Setiawan, A. and Widodo, A. 2011.

*The development of generic science skills of prospective science teachers using*

*interactive multimedia*. Paper presented at fifth international seminar of science

education, Indonesia University of

Education, Bandung, Indonesia, November

12.

Liliasari. 2010. *Redesigning Indonesian science curriculum based on generic science skills*. Paper, presented on the 4-th international seminar of science education, Indonesia University of Education, Bandung, Indonesia, 30 October.

Malone, K.L. 2008. Correlations among knowledge structures, force concept inventory, and problem-solving behaviors. *Phys. Rev. ST Phys. Educ. Res*., 4, 020107.

Mayer, R. E. & Moreno, R. 2010. Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist*, 38 (1):

43-52.

Mayer, R.E. 2005. Cognitive theory of multimedia learning, in Mayer, R.E. (ed.):

*The Cambridge Handbook of Multimedia*

*Learning,* 3148. New York: Cambridge

University Press.

Moore, J.C., & Rubbo, L.J. 2012. Scientiﬁc

reasoning abilities of nonscience majors in physics-based courses. *Physical Review Special Topic- Physics Education Research.* 8, 010106.

Morgan, G.A., Leech, N.L., Gloeckner, G.W.,

& Barrett, K.C. 2004. *SPSS for introductory statistics: Use and interpretation 2nd edition*. New Jersey, Lawrence Erlbaum Associates Inc.

Mullis, I.V.S. et al. 2009. *TIMSS 2011*

*Assessment Frameworks*. TIMSS and PIRLS International Study Center, Lynch School of Education, Boston College.

National Research Council. (1996). *National science education standards*. Washington

D.C.: National Academy of Sciences. National Research Council. 2012. *A*

*framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington D.C.: National

Academy of Sciences.

NSTA. (2011). *NSTA Standards for Science*

*Teacher Preparation*. Available: [www.nsta.org/preservice, [](http://www.nsta.org/preservice)2 January 2012]. Ogilvie, C.A. 2009. Changes in students‟ problem-solving strategies in a course that includes context-rich, multifaceted problem. *Phys. Rev. ST Phys. Educ. Res*., 5,

020102.

Prain, V., Tytler, R., & Peterson, S. 2009.

Multiple representation in learning about evaporation. *International Journal of Science Education*, 31 (6): 787- 808.

Ramlawati, Liliasari, and Wulan, A.R. 2011.

*Improving generic science skills of chemistry prospective teachers through*

*implementation of electronic portfolio*

*assessment*. Paper presented at the fifth international seminar of science education, Indonesia University of Education, Bandung, Indonesia, November 12.

Rosengrant, D., Heuvelen, A.V., & Etkina, E.

2009. Do student use and understand free- body diagrams? *Phys. Rev. ST Phys. Educ.*

*Res*., 5, 010108.

Saprudin. 2010. *Penggunaan MMI dalam pembelajaran rangkaian arus bolak-balik untuk meningkatkan keterampilan generik sains dan berpikir kritis mahasiswa*, Tesis, Indonesia University of Education: unpublished.

Sayre, E.C. et al. (2012). Learning, retention,

and forgetting of Newton‟s third law

throughout university physics. *Physical Review Special Topic - Physics Education Research.* 8, 010116

Shaffer, P.S. and McDermott, L.C. (2005). “A

research –based approach to improving students understanding of vector nature of kinematical concepts”. *American Journal of Physics.* 73, (10), 921931.

Singh, C. and Schunn, C.D. (2009).

“Connecting three pivotal concepts in K-12 science state standards and maps of

conceptual growth to research in physics

education”. *Journal of Physics Teacher*

*Education Online*, 5, (2), 1642.

Sudarmin. 2011. Model pembelajaran kimia organik terintegrasi dengan kemampuan

generik sains. *Jurnal Ilmu Pendidikan*, 17

(6): 494-503

Sutarno. 2010. *Pembelajaran medan magnet menggunakan on-line interactive*

*multimedia untuk meningkatkan keterampilan generic sains dan berpikir*

*kritis mahasiswa*, Tesis, Indonesia

University of Education: unpublished.

Sutopo, Liliasari, & Waldrip, B. 2012.

*Implementation of representational*

*approach to improve students’ reasoning ability and conceptual understanding on mechanics*. Paper presented at National Seminar of Science Education, PPS Unessa, Indonesia, January 14.

Waldrip, B., Prain, V., & Carolan, J. 2010.

Using multi-modal representations to improve learning in junior secondary

science. *Research in Science Education,*

40: 65–80.

Wijaya, A.F.C. & Ramalis, T.R. 2012.

Collaborative ranking tasks (CTR)

berbantuan e-learning untuk meningkatkan keterampilan generik sains mahasiswa calon guru fisika. *Jurnal Pendidikan Fisika Indonesia*, 8 (2): 144-151.