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# Students' problem solving skill in nuclear physics course through NPIRL

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**Abstract**: This study aimed to describe students' problem solving skill in nuclear physics course through the implementation of the Nuclear Physics Inquiry Remote Laboratory (NPIRL). This study employed a pre-experimental quantitative method. The research design was one group pretest-posttest design. The subject of the study was 14 physics students at a university in Banjarmasin, South Kalimantan. In selecting the research subjects, the researchers used purposive sampling technique. The instrument used was a problem-solving skills test in the form of an essay consisting of five questions, and each question consisted of six indicators in problem solving skill according to the Osborn-Parnes Creative Problem Solving (CPS). This research found that the N-gain of students' problem solving skill was 0.32 in the medium category. There are four indicators of problem-solving skills that are categorized as medium: objective finding, fact finding, problem finding and idea finding. Two other low-category indicators are solution finding and acceptance finding. Based on these findings, it is concluded that students' problem solving skill in nuclear physics course through NPIRL have increased.
**Keywords**: problem solving skill; NPIRL; nuclear physics

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## Introduction

Society has benefited a lot from the results of studies on nuclear technology (Yuan et al., 2017; Fu et al., 2018). One of nuclear technologies that is widely used is radiation engineering (Hachiya & Akashi, 2016). This radiation technique has been widely used in the medical world, such as X-rays, Computerized Tomography (CT)-Scans, and radiotherapy (Hachiya & Akashi, 2016), and in agriculture, like plant breeding, post-harvest handling, and pest control (Fu et al., 2018). Radiation techniques are also used in industry and mining, i.e, to measure plate thickness, pipe cracks, and the thickness of mine layers (Jho et al., 2014).

Nuclear technology is also widely used in fission reaction utilization. This technology is utilized in the energy sector, namely Nuclear Power Plants. Furthermore, it is also used in the military field, namely in nuclear-powered submarines and the manufacture of nuclear weapons (Balart, 2017; Fu et al., 2018). In addition, the type of nuclear technology that is also widely used is radioactive dating in geology, archaeology, and anthropology, to estimate the age of fossils, artifacts, or other carbon-containing objects (Fu et al., 2018).

Even though the utilization of nuclear technology has many benefits, people's mindsets are still dominated by the fear of taking risks (Bird et al., 2014). In society, nuclear energy is often associated with danger and has negative effects (Bird et al., 2014; Kwok et al., 2017; Mah et al., 2014; Sun et al., 2014; Yuan et al., 2015; Roh & Kim, 2017; Stefanelli et al., 2017). Nuclear negative effects on people's mindsets can affect public acceptance of a country's nuclear technology utilization program (Bird et al., 2014; Nguyen & Yim, 2018).

The emergence of challenges to the negative effects of nuclear energy can be answered through education (Bhanthumnavin & Bhanthumnavin, 2014; Han et al., 2014; Brown, 2018; Hartini & Liliasari, 2020; Hartini et al., 2021). The relationship between an understanding of nuclear physics and the world around it, is that a good understanding of nuclear physics helps prepare people to participate in critical discussions in areas such as national security, energy policy, and environmental protection (OECD, 2015).

Nuclear technology is found in the discussion of Nuclear Physics which is a branch of physics. Nuclear Physics course at several the institute of teacher training in Indonesia are in the Introduction to Nuclear Physics course (Hartini & Liliasari, 2020). Several studies have shown that students' high-order thinking skills are in the low category in Nuclear Physics course (Cherney et al., 2005; Hartini & Liliasari, 2020). Based on the results of a preliminary study conducted on 23 physics students at a university in Banjarmasin, on one of the higher order thinking skills, namely problem solving skill, is classified as low with an average score of 16.17 out of a maximum score of 100. Problem-solving skills are one of the foundations of 21st century learning (Sinaga et al., 2022). Problem solving skills are also one of the important competencies expected of college graduates (Klegeris et al., 2017).

One form of lecture activity to train thinking skills in order to overcome these problems is inquiry. Inquiry learning is learning that habits students to learn and solve problems, assume, and be responsible for achieving understanding independently (Jerrim et al., 2022). Inquiry-based learning requires learners to develop questions and hypotheses, collect data, analyze data, communicate and draw conclusions (Cairns, 2019). Using these activities, students are assumed to be scientists who are conducting experiments, and therefore higher-order thinking patterns can be built. The use of inquiry learning has a positive effect on problem solving skills (Abaniel, 2021; Wu et al., 2021). One type of inquiry stage is the inquiry laboratory activities (Wenning, 2005). The inquiry laboratory model can be used as a means to confront students' preconceptions (Srisawasdi & Kroothkeaw, 2014).

Apart from that, in the Nuclear Physics course, doing real laboratory activities is also difficult and limited (Eddahby et al., 2019). In this practicum, sophisticated equipment is required, the equipment is expensive, maintenance is difficult, and there are fears of being exposed to radiation when doing the practicum (Karpudewan & Chong, 2018; Malkawi & Al-Araidah, 2013). The development of information technology has changed the view of laboratory activities towards the use of traditional laboratories. One of them is a remote laboratory (RL). RL is an activity conducted in a real laboratory that is connected to experimenters remotely via a network (Bhute et al., 2021). RL provides extensive experiment accessibility without time constraints, allowing students to operate experiments remotely and manipulate experiment variables (Karpudewan & Chong, 2018).

Remote laboratory activities for nuclear physics have been developed and implemented by Malkawi & Al-Araidah (2013) namely the use of the Internet Reactor Laboratory (IRL) between the PULSTAR research reactor at North Carolina State University in the United States and the Department of Nuclear Engineering at Jordan University of Science and Technology (JUST) in Jordan; Saldikov et al., (2017) developed the Open Web System of Virtual Labs for Nuclear and Applied Physics which is part of the Cyber Learning Platform for Nuclear Education (CLP4NET); Yakovlev et al.,( 2017) carried out the development of CLP4NET by integrating it into educational technology; Karpudewan & Chong, (2018) implemented Radioactivity Remote Laboratory Activities (RRLA); Syarip et al., (2018) developed Kartini's Internet Reactor Laboratory (IRL) for nuclear education and training programs which were then continued by Taxwim et al.,( 2020) that implementing IRL Kartini as a remote laboratory for laboratory activities in the university. However, the results of research on remote laboratories in Nuclear Physics have not yet trained the steps of inquiry in their implementation.

Based on these problems, a nuclear physics course program is presented using the principle of inquiry and a remote laboratory type, namely through the Nuclear Physics Inquiry Remote Laboratory (NPIRL). From previous research using the Nuclear Physics Inquiry Virtual Laboratory (NIVPL) it was obtained that lectures by implementing NPIVL could improve higher-order thinking skills, namely critical thinking skills (Hartini et al., 2022). The Nuclear Physics course program through NPIRL is carried out in two stages. Pre-laboratory activity is the first phase of the lecturing program through the NPIRL. This stage trains the activity of the incur which is an open question. Laboratory activities are the second activity on the lecture program through NPIRL. This stage trains inquiry activities, i.e. giving open questions, formulating predictions, designing experiments, conducting experimentation, collecting and analyzing data, and drawing conclusions based on the results of research. At both stages, higher-order thinking skills are trained, namely problem solving.

Based on this background, research was conducted on problem solving skills in nuclear physics course through NIPRL. The purpose of this study was to describe the problem solving skills of physics students in nuclear physics course through NPIRL. This research is expected to contribute to equipping students with higher order thinking skills. Students who have high-order thinking skills can become active citizens in solving problems facing the era of society 5.0.

## Method

The method used in this study was pre-experimental quantitative. Table 1 depicts the design of the study using one group pretest-posttest (Creswell & Guetterman, 2019) with O1: pretest score before implementing the course program through NPIRL; O2: posttest score after the implementation of the course program through NPIRL; and X: implementation of course program through NPIRL.

**Table 1. One group pretest-posttest research design**

| Pretest | Treatment | Posttest |
|---|---|---|
| $O_1$ | X | $O_2$ |

The implementation of the course program through NPIRL was carried out by 14 physics students at a university in Banjarmasin. The selection of research subjects used a purposive sampling technique. Before the implementation of the course program through NPIRL was carried out, students first worked on a pre-test. Then, after the implementation of the course program, students did the post-test. Based on the results of the pre-test and post-test analyses, an increase in students' problem solving skill can be seen. The indicators of problem solving skill used refer to The Osborn-Parnes Creative Problem Solving (CPS) Model namely objective finding, fact finding, problem finding, idea finding, solution finding, and acceptance finding.

In collecting the research data, an essay test instrument was used. There were five questions on the test and each question consisted of six questions according to the problem solving skills indicator from the Osborn-Parnes. The increase in problem solving ability was determined by normalized N-gain based on equation (1) (Hake, 1998):

$$< \boldsymbol{g} > = \frac{\%\langle \boldsymbol{G}\rangle}{\%\langle \boldsymbol{G}\rangle_{\boldsymbol{max}}} = \frac{(\%\langle \boldsymbol{s_f}\rangle - \%\langle \boldsymbol{s_i}\rangle}{(\boldsymbol{100} - \%\langle \boldsymbol{s_i}\rangle} \qquad (1)$$

with: $\langle g\rangle$ = normalized average gain; $\langle G\rangle$= average actual gain; $\langle G\rangle_{max}$= average maximum possible gain; $\langle s_f\rangle$= average posttest score rata-rata; and $\langle s_i\rangle$ = average pretest score. The criteria for the normalized gain value $\langle \boldsymbol{g}\rangle$ can be seen in Table 2.

**Table 2. Normalized gain value criteria (Hake, 1998)**

| Value <g> | Classification |
|---|---|
| $<g> \geq 0.7$ | High |
| $0.7 > <g> \geq 0.3$ | Medium |
| $<g> < 0.3$ | Low |

## Results and Discussion

The purpose of this research was to describe the problem solving skills of physics students in the nuclear physics lecture course NPIRL. Problem solving skills are trained through the inquiry stage in pre-laboratory and laboratory activities. The use of a remote laboratory in this study used a remote laboratory from the Center of Science and Accelerator Technology (PSTA) of the National Nuclear Energy Agency (Batan) of the Indonesian National Research and Innovation Agency (BRIN), namely Kartini's Internet Reactor Laboratory (IRL). The laboratory activities used in the fission reactions course, namely fission reactors, include reactor power calibration, neutron flux measurement, control rod calibration, fuel temperature reactivity coefficient and reactor criticality. Figure 1 shows the IRL display of Kartini at the time of the reactor power calibration practicum.

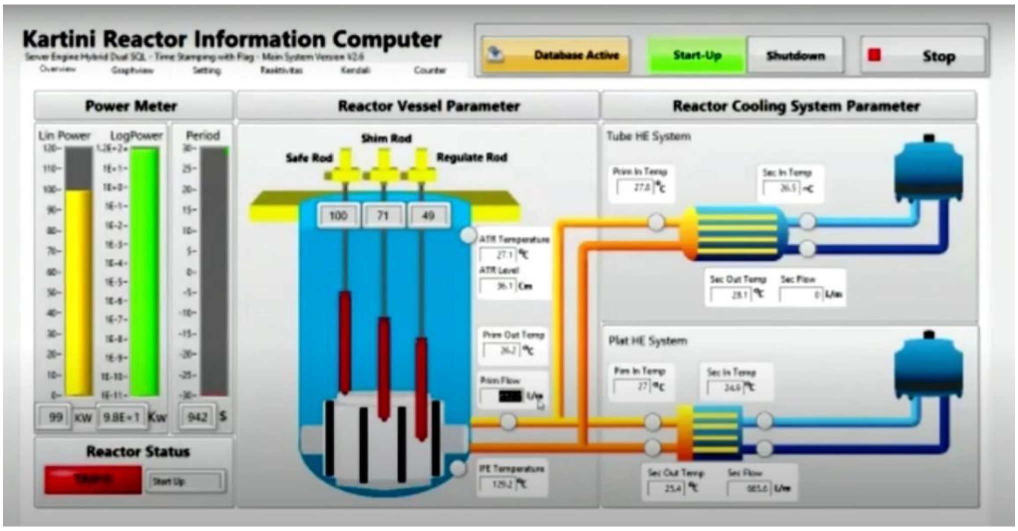


**Figure 1. IRL Kartini in the reactor power calibration practicum**

The normalized N-gain value was used to measure the increase in problem solving abilities. The normalized value of N gain can be seen in Table 3.

**Table 3. Normalized N-gain value**

| Pretest | Posttest | N-gain | Category |
|---|---|---|---|
| 4.73 | 35.48 | 0.32 | Medium |

Table 3 shows that the average post-test score increased when compared to the pre-test score with a normalized N-gain of 0.32 in the medium category. This is inseparable from the implementation of NPIRL in course programs. The NIPRL program is a course program based on inquiry-based laboratory activities stages. The stages of inquiry laboratory activities at NPIRL to practice problem solving skills are (1) give open questions: students formulate research questions; (2) formulate predictions: students make research hypotheses; (3) design the experiment: students design practicum steps and data tables of practicum results; (4) conduct the experiment: students conduct practicum according to the practicum design that has been made; (5) collect and analyse the data: students collect practicum data, analyze data, and perform interpretations; (6) draw conclusions: students draw the conclusions based on the research results of the current practicum. Several studies have shown that inquiry learning has a positive effect on problem-solving skills (Abaniel, 2021; Wu et al., 2021). Developing problem-solving skills is a key factor in science (Ceberio, et al., 2016).

Inquiry learning is learning using a constructivist approach. Based on this approach, students carry out inquiry activities, namely asking questions and conducting investigations using various resources (Abaniel, 2021). One of them is with digital technology (Wu et al., 2021). The digital technology that can be utilized is the remote laboratory (RL). RL is a laboratory activity conducted in a real laboratory that is connected to experimenters remotely via a network (Alkhaldi et al., 2016).

Through RL, students are given experience operating experiments independently, thereby indirectly encouraging independent learning (Gröber et al., 2014), and fostering constructivism learning (Bhute et al., 2021). Apart from involving digital technology, this lecture program involves a nuclear facility, namely IRL Kartini from Batan BRIN Indonesia. Learning nuclear physics, especially nuclear science and technology by involving nuclear facilities that have been developed in various countries, can increase student and public knowledge about nuclear physics (Yakovlev et al., 2017; Karpudewan & Chong, 2018).

There is an increase in the average posttest score compared to the pretest score based on Table 3, but the increase in problem solving skills was not optimal because the increase in each indicator of problem-solving skills was uneven. The N-Gain achievement of each indicator of problem-solving skills will be described in Table 4.

**Table 4. Achievement of problem-solving skill each indicator**

| Indicator of Problem-Solving Skill | Pre test | Post test | N-Gain |
|---|---|---|---|
| Objective finding | 8.32 | 58.57 | 0.55 |
| Fact Finding | 11.86 | 53.93 | 0.47 |
| Problem Finding | 6.64 | 50.00 | 0.46 |
| Idea Finding | 2.00 | 38.57 | 0.37 |
| Solution finding | 0.18 | 11.79 | 0.12 |
| Acceptance Finding | 0.14 | 1.43 | 0.01 |

Table 4 shows each indicator of improved problem-solving skills based on pre-test and posttest results. From the results of the pretest, the largest indicator value of critical problem-solving skills was fact finding and the smallest was acceptance finding. From the results of the posttest, the largest indicator value of problem-solving skills was objective finding and the smallest was acceptance finding. There was a difference between the results of the pretest and posttest, namely that in the pretest the largest indicator value was fact finding, while in the posttest, the largest indicator value was objective finding. Table 4 also shows the N-gain which was in the moderate category in the indicators of objective finding, fact finding, problem finding, and idea finding, while the solution and acceptance finding indicators were in the low category.

Based on Table 4, the N-Gain value in the objective finding indicator is 0.55 in the moderate category. The stage that students perform on the indicator is to find a problem that is perceived as an interference, is an attempt to identify a situation that is felt to hinder things. Figure 2 is a representative answer from students on one of the questions for the question items based on the objective finding indicators.

**Question:** After reading the information above, in your opinion, what are the challenges faced by Rani in calibrating the reactor power? Determine the main challenges faced by Rani.
**Answer:**
**Challenge:**
1. Determine the reactor power using the nuclear method
2. Determine the reactor power using the stationary calorimeter method
3. Determine the reactor power using the non-stationary calorimeter method

**Main Challenge:**
Determine the reactor power using the non-stationary calorimeter method.

**Figure 2. Student answers to determine the challenges based on the description of the challenges in the Reactor Power Calibration course**

Figure 2 is the students' answers to determine the challenges based on the description of the challenges in the Reactor Power Calibration course. In this section, there are representatives that students are able to express the challenges faced in the description of challenges regarding reactor power calibration, namely that reactor power can be determined using the nuclear method, the stationary calorimeter method and the non-stationary calorimeter method. Students are able to determine the priority of challenges among the three challenges that have been disclosed.

The N-Gain value from Table 4 for the fact-finding indicator is 0.47 in the moderate category. The stage that students perform on such indicators is to find all known facts related to a situation necessary to identify essential information unknown to that situation. Figure 3 is a representative answer from students on one of the questions items based on the fact- finding indicator.

**Question:** What information do you think affected the situation that needs to be recorded? Prioritize the information based on its impact on the challenges you prioritize.

**Influential information:**

1. Nuclear power calibration is carried out by measuring the neutron flux directly on each fuel element, and can only be done at low power operation.
2. Calibration of power using the calorimetry method, namely measuring the temperature rise of the cooling water caused by the heat of fission in the reactor core which is transferred to the cooling water.
3. Calibration by calorimetry two two kinds: non-stationary and stationary. In the stationary method, the reactor is operated with the cooling system running. In the non-stationary method, the reactor is operated with the cooling system not running

**Priority information:**

There are two types of calibration by calorimetry, namely non-stationary and stationary. In the stationary method, the reactor is operated with the cooling system running. In the non-stationary method, the reactor is operated with the cooling system not running.

**Figure 3. Students' answers to determine the information that influences the description of the challenges of the Reactor Power Calibration course**

Figure 3 shows the students' answers to determine influential information based on the description of the challenges in the Reactor Power Calibration course. In this section, the students were asked to find important information and determine the information that is a priority in the calibration activities of the reactor power. There were representatives in which students were able to determine influential information based on the description of challenges regarding reactor power calibration and were able to determine priority information/ facts.

Then, Table 4 also shows the N-Gain value for the problem finding indicator is 0.46 in the moderate category. It is the stage that the students performed on such indicators to identify all possible problem statements and then select the most important or underlying problem. Figure 4 is a representative answer from students on one of the questions items based on the problem finding indicator.

**Question:** What problems do you think might be faced? Determine the main problem based on the challenges you prioritize

**Possible problem:**

1. How to determine the reactor power using the nuclear method.
2. How to determine the reactor power using the stationary calorimeter method.
3. How to determine the reactor power using the non-stationary calorimeter method.

**Priority problem:**

How to determine reactor power using non-stationary calorimeter method.

**Figure 4. Student's answer to determine the problem based on the description of the challenges in the Reactor Power Calibration course**

Figure 4 is the student's answer to determine the problem based on the description of the challenge in the Reactor Power Calibration course. In this section, the students were asked to formulate the problem and determine the formula of the problem that is a priority in the calibration activities of the reactor power. There were some students who were able to determine problems based on the description of challenges regarding reactor power calibration and were able to determine priority information/facts.

The N-Gain value from Table 4 for the idea finding indicator is 0.37 in the moderate category. The stage that the students performed on this indicator was to find a number of ideas or problem-solving ideas. Figure 5 is a representative answer from students on one of the question items based on the idea finding indicator.

**Question**: What ideas might be done to solve the problem? Please explain! Find your main idea based on the problem you choose.
**Possible ideas:**
1. To determine the reactor power using the nuclear method by measuring the flux of neutrons in the reactor core.
2. To determine the reactor power using the stationary calorimeter method is by measuring the temperature of the water leaving and entering the reactor core
3. To determine the reactor power using the non-stationary calorimeter method is by measuring the rate of rise of the tank water temperature at a constant reactor power level.

**Selected main ideas:**
To determine the reactor power using the non-stationary calorimeter method is by measuring the rate of rise of the tank water temperature at a constant reactor power level.

**Figure 5. Student's answer to determine possible ideas based on the description of the challenges of the Reactor Power Calibration course**

Figure 5 is the students' answers to determine ideas that might be carried out based on the description of the challenges in the Reactor Power Calibration course. Students were asked to find as many ideas as possible to solve reactor power calibration problems and determine the main ideas to be solved. In this section there were student representatives who were able to find three ideas based on the description of the challenges regarding reactor power calibration and chose the main ideas to be resolved.

The N-Gain value from Table 4 for the solution finding indicator is 0.12 in the low category. The students selected thoughts or ideas to solve problems as performed on this indicator in this stage. Figure 6 is a representative of the answers from students on one of the questions items based on the solution finding indicator.

**Question**: Find the ultimate solution based on the problem you are facing!
**Solution:**
The solution to determine the reactor power using a non-stationary colorimetric method, is by using the equation $P = \frac{dQ}{dt} = H\frac{dT}{dt}$.

**Figure 6. Student's answer to determine solutions that are carried out based on the problems faced by the description of the challenges of the Reactor Power Calibration course**

Figure 6 depicts the students' answers to determine possible solutions based on the description of the challenges in the Reactor Power Calibration course. The students are asked to find solutions to the calibration activity of the reactor power. In this section, most of the students were unable to strengthen their ideas and formulate the main solutions for reactor power calibration.

N-Gain value from Table 4 for the acceptance finding indicator is 0.01 in the low category. The stage that students undertake on this indicator is to find acceptance of problem solutions, formulate a plan of action and implement the solution in solving problems. Figure 7 shows a representative answer from students on one of the question items based on the acceptance finding indicator.

| |
|---|
| **Question:** What are the strengths and weaknesses of the solution you offer? Please explain!<br>**Strength:** when measuring the temperature rise of the reactor water the reactor cooling system was not operated |

**Figure 7. Student's answer to determine the strengths and weaknesses of the solutions offered based on the description of the challenges of the Reactor Power Calibration course**

Figure 7 provides the students' answers to determine the strengths and weaknesses of the solutions offered in the Reactor Power Calibration course. The students are asked to determine the strengths and weaknesses of the chosen solution. Most students were unable to identify the strengths and weaknesses of the solutions offered in reactor power calibration. They only wrote down the strengths of the solution and did not write down the weaknesses of the solution offered.

Based on the results of the study, the N-Gain on objective, fact, problem, and idea finding indicators is in the medium category. This shows that students have been able to form a good understanding of the three indicators. The stages in the thinking process begin with the stages of forming understanding, then forming opinions, and forming conclusions (Holt, 2018; Swanson & Collins, 2018). In this case, the best effort the students can make is to prepare the preparation stage well, which is to formulate important information about the description of the challenge and re-read the description. It aims to establish the intention of the author using the information available in the text and assisted by the previous knowledge and experience of the student (Yazdanpanah, 2007).

The N-Gain indicators of problem finding and acceptance finding are in the low category. Students have difficulty finding ideas in solving problems using the right solution. People who can find varied problem solving strategies are good problem solvers (Leung & Kember, 2003; Cheng et al., 2018). Problem solving skills are the ability to find solutions through the process of obtaining and organizing information (Hull et al., 2013). In problem solving skills, forming knowledge requires various cognitive activities in obtaining and organizing information (Cheng et al., 2018; Wu et al., 2021). In solving problems, involving previous and new knowledge, namely by activating previous knowledge with new knowledge so that it can solve problems (Wu et al., 2021).

## Conclusion

Based on the results of the study, the N-Gain results of students' problem-solving skills were 0.32 in the medium category. The N-gain results for each indicator of problem-solving skills in the medium category are objective finding, fact finding, problem finding, and idea finding, and in the low category are solution finding and acceptance finding. Thus, it is concluded that students' problem-solving skills in nuclear physics course through NPIRL have increased. This research has limitations that was carried out at a limited trial stage and the course was only on fission reactions. For further research, it can be implemented in broader research and implemented in other higher-order thinking skills.

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