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Stacking-Racking Analysis: Improving Physics Students' Problem-Solving Skills with ECIRR Learning Model and a Metacognitive Approach

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Abstract *– A preliminary study highlights the persistent challenge of low problem-solving skills among 21st-century students. Therefore, this study examines the ECIRR learning model with a metacognitive approach to improve students' problem-solving skills in static fluid material. The method of this study is quasi-experimental with a one-group pretest-posttest design, enrolling 33 students from class XI at a public high school in Subang City. The Static Fluids Problem Solving Test (SPRING) instrument is used to collect data, which will then be analyzed using the stacking-racking technique. The results showed that ECIRR model learning with a metacognitive approach significantly improved students' problem-solving skills by 2.66 on the logit scale in the moderate category. The highest increase in problem-solving skills was on the plan a solution indicator, and the lowest was on the visualize the problem indicator. The decrease in the level of difficulty of the SPRING instrument indicates that learning has a positive impact. Thus, ECIRR model learning with a metacognitive approach can improve student problem-solving skills in a static fluid material. This study can be strengthened by using a control class to compare the results obtained in the control and experimental groups so that the effectiveness of the intervention can be determined objectively.*

Keywords*: ECIRR model; Metacognitive Approach; Problem-Solving Skills; Stacking-Racking Analysis*

INTRODUCTION

Physics learning in schools significantly contributes to equipping students with problem-solving skills, one recognized as a crucial 21st-century skill (Saka et al., 2024). Problem-solving skills are important for students, as they help them tackle challenges in the classroom and life (Liana et al., 2023). The physics learning process aims to empower students to solve real-world problems by developing their ability to discover facts, construct concepts, and apply scientific principles (Darwis, 2018; Niss, 2012; Wider & Wider, 2023). However, several studies have found that one of the obstacles in learning physics is students' difficulty in solving problems.

A preliminary study was undertaken at a high school in Subang City to examine student proficiency in problem-solving and investigate potential causes of identified difficulties. The results showed that the average problem-solving skills of 31 respondents who participated were 32.42 on a scale of 0 to 100, with the highest value being 55 and the lowest value being 20. This figure shows that students' problem-solving skills are still meager and need to improve. The highest indicator of students' problem-solving skills is the ability to execute the plan, while the lowest is the ability to check and evaluate the solution. A survey of students revealed that physics learning remains largely teacher-centered. Furthermore, based on the results of an interview with one of the physics teachers at the school, the low problem-solving ability of students is caused by a lack of understanding of physics concepts and the assumption that physics is just a formula.

The aforementioned information is further corroborated by findings from multiple studies exploring the underlying causes of students' low problem-solving abilities. Factors causing low problem-solving skills include: the physics learning process in schools is still teacher-centered (Yulianawati et al., 2016); teachers have yet to use learning media that can motivate students (Ardiansyah et al., 2019); and students cannot collect data and information properly (Januarifin et al., 2017). To overcome this, Jayadi et al. (2020) suggested a solution to improve the quality of learning that solidifies physics concepts, encourages student participation, and empowers student metacognition.

One of the learning alternatives that can be used to improve problem-solving skills is the ECIRR (Elicit, Confront, Identify, Resolve, Reinforce) learning model, which adheres to constructivism and emphasizes student cognitive conflict (Ardiansyah et al., 2019). The ECIRR learning model, as proposed by Wenning (2008), comprises five sequential stages. The first stage, elicit, aims to uncover students' prior knowledge. The second stage, confront, utilizes demonstrations or questions to challenge students' initial conceptions and induce cognitive conflict. The third stage, identify, facilitates students in explaining and justifying their initial ideas. The fourth stage, resolve, empowers students to overcome cognitive conflict through experimentation. The fifth stage, reinforce, serves to solidify student learning through positive feedback. The ECIRR learning model can help students understand abstract concepts, correct erroneous conceptions, facilitate interaction and work with friends to help overcome each other's difficulties, and make learning more meaningful and give a long-term impression (Hamdani, 2014).

When models are presented without metacognitive skills, students have difficulty connecting them to real-world phenomena (Wade-Jaimes et al., 2018). According to Mayer (Güner & Erbay, 2021), problem-solving requires not only cognitive skills and knowledge but also metacognitive skills that involve knowing when and how to use cognitive resources. Metacognitive skills involve a set of individual learner abilities, such as self-regulation skills, that allow them to assess whether the learning strategies they are using are effective for solving the problem at hand (Tachie, 2019). Regulation of cognitive activity is necessary because cognitive abilities cannot run by themselves (Novia et al., 2016). Within the learning domain, metacognition plays a crucial role in promoting awareness of one's thought patterns and how they influence understanding (Sucinta et al., 2016). Metacognitive is very important for solving problems so that cognitive functions can be used effectively (Novia et al., 2016). Learning with a metacognitive approach prioritizes student learning activities, helps students if they have difficulties, and helps students develop a self-concept of what they do when learning (Iskandar, 2014).

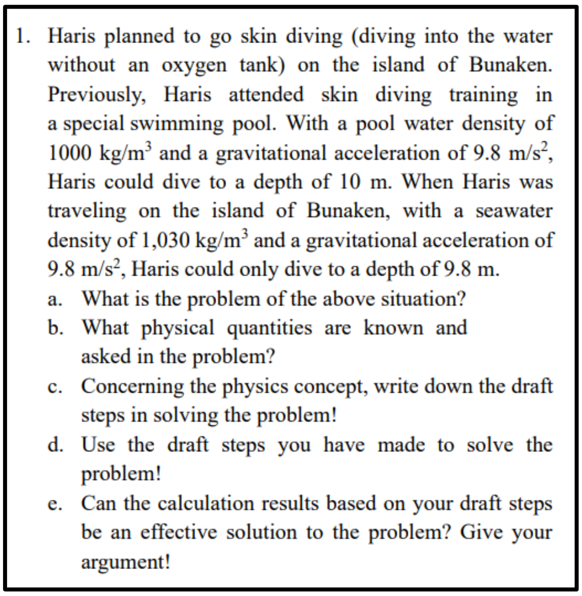
Based on this description, one learning alternative that can be implemented to improve problem-solving skills is the ECIRR learning model integrated with a metacognitive approach. To enable precise and accurate measurement, acquire information on measuring changes at the level of individual students and items, assess intervention impact, and gain deeper understanding, the stacking-racking analysis technique should be employed (Davidowitz & Potgieter, 2016; Laliyo, 2021; Park & Liu, 2021; Pentecost & Barbera, 2013; Sukarelawan et al., 2024). Stacking analysis is a longitudinal technique used to compare learners' abilities before and after intervention (Sukarelawan et al., 2024). Racking analysis is an analytical technique used to compare the items' difficulty levels before and after the intervention (Laliyo, 2021). Thus, this study aims to examine the impact of ECIRR model learning with a metacognitive approach on improving students' problem-solving skills by using the stacking analysis technique.

RESEARCH METHODS

This study used a quasi-experimental design with a one-group pretest-posttest model. The accessible population consisted of all grade XI students at a high school in Subang City. A convenience sampling technique was employed to select a sample of participants. The Physics teacher selected a class of 33 grade XI students. The class comprised 23 female students and 10 male students, and none had been taught about static fluids.

A pretest was conducted before the intervention to assess students' initial skills in solving physics problems. The intervention itself involved applying the ECIRR (Elicit, Confront, Identify, Resolve, Reinforce) model with a metacognitive approach during the learning process. At the elicit stage, teachers explore the initial knowledge of students by providing stimuli in the form of questions about a static fluid phenomenon. Furthermore, at the confront stage, teachers confront learners' initial conceptions through implications and questions that cause learners to experience cognitive conflict. At the identify stage, teachers provide opportunities for learners to explain and defend their initial thoughts. Then at the resolve, learners overcome cognitive conflict through experimentation. Finally, at the reinforce stage, the teacher provides reinforcement. In the end, a posttest was conducted to evaluate students' physics problem-solving skills after the intervention.

This study measured students' problem-solving skills using an essay instrument called the Static Fluids Problem Solving Test (SPRING). The SPRING instrument consists of three items: hydrostatic pressure, Pascal's Law, buoyancy force and Archimedes' Law. In each item, five questions are adaptations of problem-solving stages according to Heller et al. (1992): visualize the problem, describe the problem in physics terms, plan a solution, execute the plan, check and evaluate the solution.



1. Haris planned to go skin diving (diving into the water without an oxygen tank) on the island of Bunaken. Previously, Haris attended skin diving training in a special swimming pool. With a pool water density of 1000 kg/m^3 and a gravitational acceleration of 9.8 m/s^2, Haris could dive to a depth of 10 m. When Haris was traveling on the island of Bunaken, with a seawater density of 1,030 kg/m^3 and a gravitational acceleration of 9.8 m/s^2, Haris could only dive to a depth of 9.8 m.
    a. What is the problem of the above situation?
    b. What physical quantities are known and asked in the problem?
    c. Concerning the physics concept, write down the draft steps in solving the problem!
    d. Use the draft steps you have made to solve the problem!
    e. Can the calculation results based on your draft steps be an effective solution to the problem? Give your argument!

Figure 1. Examples of SPRING Instruments

Students' pretest-posttest data were then processed and analyzed using the stacking-racking technique. Students' pretest and posttest data were collected simultaneously, and then the raw data was converted into the same interval scale (logit). Changes in students' abilities are seen based on changes in the location of the ability level on the vertical ruler and changes in logit values in Minifac software version 3.87.0. Stacking analysis allows researchers to see changes in students' abilities over time in more depth, especially after intervention (Sukarelawan et al., 2024). Like the stacking technique, students' pretest and posttest data were collected simultaneously, and then the raw data were converted into the same interval scale (logit). Changes in the size of item difficulty are seen based on changes in item location on the vertical ruler and logit values in Minifac software version 3.87.0.

RESULTS AND DISCUSSION

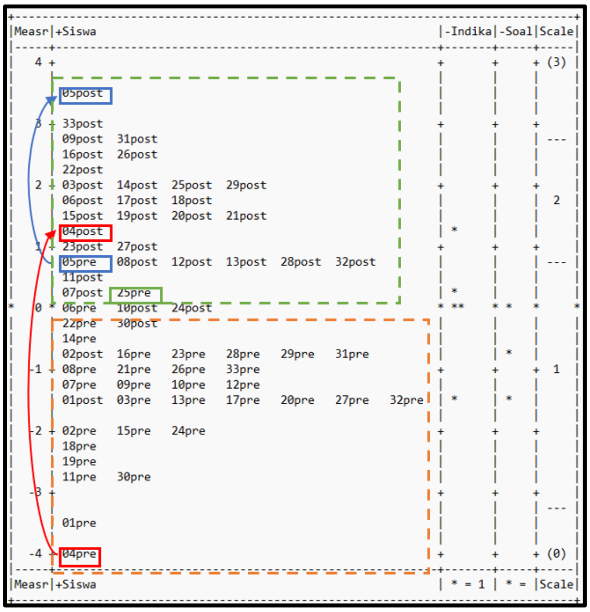
Stacking Analysis

The stacking analysis technique compares students' problem-solving abilities before and after the ECIRR (Elicit, Confront, Identify, Resolve, Reinforce) learning model with a metacognitive approach implemented. Students' problem-solving skills are represented using logit values. A positive change in the logit value indicates an increase in student abilities, while a negative category indicates a decrease in student abilities (Laliyo, 2021). To facilitate tabulation, students are given codes according to sequence number and gender. The student pretest and posttest data analysis results are presented in Table 1 below.

Table 1. Measures of Problem-Solving Skills Changes

Person	Measure		Difference	Category
	Pre	Post		
01P	-3.39	-1.42	1.97	Positive
02P	-1.95	-0.74	1.21	Positive
03P	-1.42	1.94	3.36	Positive
04L	-3.39	1.27	4.66	Positive
05P	0.81	3.40	2.59	Positive
06P	0.00	1.76	1.76	Positive
07P	-1.18	0.17	1.35	Positive
08P	-0.96	0.81	1.77	Positive
09P	-1.18	2.78	3.96	Positive
10P	-1.18	0.00	1.18	Positive
11P	-2.80	0.49	3.29	Positive
12P	-1.18	0.81	1.99	Positive
13P	-1.42	0.65	2.07	Positive
14P	-0.54	2.12	2.66	Positive
15L	-1.95	1.59	3.54	Positive
16L	-0.74	2.54	3.28	Positive
17L	-1.42	1.76	3.18	Positive
18L	-2.22	1.76	3.98	Positive
19L	-2.51	1.43	3.94	Positive
20P	-1.42	1.59	3.01	Positive
21P	-0.96	1.43	2.39	Positive
22P	-0.35	2.32	2.67	Positive
23P	-0.74	0.96	1.70	Positive
24P	-1.95	0.00	1.95	Positive
25P	0.17	2.12	1.95	Positive
26P	-0.96	2.54	3.50	Positive
27P	-1.42	0.96	2.38	Positive
28L	-0.74	0.65	1.39	Positive
29P	-0.74	2.12	2.86	Positive
30L	-2.80	-0.17	2.63	Positive
31L	-0.74	2.78	3.52	Positive
32L	-1.42	0.81	2.23	Positive
33P	-0.96	3.06	4.02	Positive
Mean	-1.32	1.34	2.66	Positive

The positive change in posttest-pretest logit scores for all students indicates that all students experienced increased problem-solving abilities. Changes in students' problem-solving skills can also be seen through vertical ruler analysis, which visualizes the location of students' ability levels during the pretest and posttest (Sukarelawan et al., 2024). The vertical ruler analysis is shown in Figure 2 below.



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|     | 05post                                                |       |     |     |
|     |                                                       |       |     |     |
|   3 + 33post                                                +       +     +     |
|     | 09post  31post                                        |       |     | --- |
|     | 16post  26post                                        |       |     |     |
|     | 22post                                                |       |     |     |
|   2 + 03post  14post  25post  29post                        +       +     +     |
|     | 06post  17post  18post                                |       |     |  2  |
|     | 15post  19post  20post  21post                        |       |     |     |
|     | 04post                                                | *     |     |     |
|   1 + 23post  27post                                        +       +     +     |
|     | 05pre   08post  12post  13post  28post  32post        |       |     | --- |
|     | 11post                                                |       |     |     |
|     | 07post  25pre                                         | *     |     |     |
*   0 * 06pre   10post  24post                                * **    * *   *     *
|     | 22pre   30post                                        |       |     |     |
|     | 14pre                                                 |       |     |     |
|     | 02post  16pre   23pre   28pre   29pre   31pre         |       | *   |     |
|  -1 + 08pre   21pre   26pre   33pre                         +       +     +  1  |
|     | 07pre   09pre   10pre   12pre                         |       |     |     |
|     | 01post  03pre   13pre   17pre   20pre   27pre   32pre |  *    | *   |     |
|     |                                                       |       |     |     |
|  -2 + 02pre   15pre   24pre                                 +       +     +     |
|     | 18pre                                                 |       |     |     |
|     | 19pre                                                 |       |     |     |
|     | 11pre   30pre                                         |       |     |     |
|  -3 +                                                       +       +     +     |
|     |                                                       |       |     | --- |
|     | 01pre                                                 |       |     |     |
|     |                                                       |       |     |     |
|  -4 + 04pre                                                 +       +     + (0) |
|-----+-------------------------------------------------------+-------+-----+-----|
|Measr|+Siswa                                                 | * = 1 | * = |Scale|
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Figure 2. Vertical Ruler of Problem-Solving Skills Changes

The location of students' problem-solving ability levels during the pretest and posttest is listed in the second column on the left. The pre-code after the serial number encodes the student's ability during the pretest, while the post-code after the serial number encodes the student's ability during the posttest. Students' problem-solving skills range from -4 to +4 logit scale. The problem-solving ability of student number 04L during the pretest was the lowest. The distribution of students with low problem-solving ability fails at the bottom left. In contrast, the distribution of students with high problem-solving ability fails at the top left (Sukarelawan et al., 2024).

In Figure 2, the distribution of students' low problem-solving abilities is the students' initial abilities before the intervention (during the pretest). However, two students who showed high problem-solving skills during the pretest were students 05P and 25P. The student with serial number 05P had the highest problem-solving skills during the posttest. After completing the intervention, students who were still distributed with low problem-solving abilities were 01P, 02P, and 30P.

The distribution of students' problem-solving ability levels after the intervention became wider than before the intervention. This shows that ECIRR model learning with a metacognitive approach does not homogeneously improve students' problem-solving abilities. For this reason, it is necessary to group students' ability levels to see the significance of the influence of the ECIRR model with a metacognitive approach on problem-solving abilities using standard deviation values. With the standard deviation value obtained at 1.70 and the average logit value at 2.66 on the logit scale, the grouping results for increasing students' problem-solving abilities are presented in Table 2 below.

Table 2. Grouping Results of Improving Problem-Solving Ability

Category	Person
Outlier	-
Very High	04L
High	03P, 09P, 11P, 15L, 16L, 17L, 18L, 19L, 20P, 22P, 26P, 29P, 31L, 33P
Moderate	01P, 02P, 05P, 06P, 07P, 08P, 10P, 12P, 13P, 14P, 21P, 23P, 24P, 25P, 27P, 28L, 30L, 32L
Low	-
Outlier	-

Based on Table 2, the distribution of increases in students' problem-solving abilities is only in the very high, high, and moderate category. Student 04L was the only student who experienced increased problem-solving skills in the very high category. The increase in problem-solving abilities of 05P students, who had the highest abilities at the pretest and posttest, was in the moderate category. This aligns with Batha & Carroll (2007) research findings, which showed no significant influence between metacognition and problem-solving abilities in the above-average group. Galotti believes this can be caused by excessive self-confidence, so they think they do not need the available help (Batha & Carroll, 2007). This condition also applies to 25P students with high problem-solving abilities during the pretest and posttest.

The increase in students' problem-solving abilities for each indicator is shown in Table 3 below.

Table 3. Size and Category of Change in Level of Problem-Solving Ability for Each Indicator

Indicator	Measure		Diff.	Category
	Pre	Post		
Visualize the problem	0.65	2.29	1.64	Moderate
Describe the problem in physics terms	-1.59	1.43	3.02	High
Plan a solution	-2.01	2.02	4.03	High
Execute the plan	-1.63	1.19	2.82	High
Check and evaluate the solution	-2.09	-0.26	1.83	Moderate

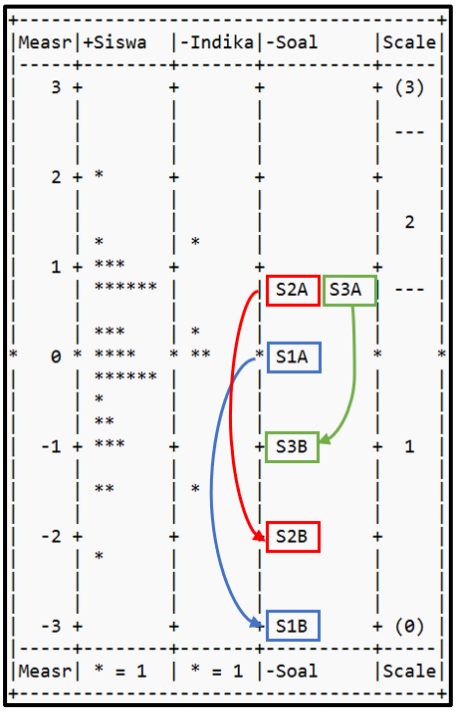
Table 3 shows that the increase in students' ability to describe the problem in physics terms, plan a solution, and execute the plan is in the high category. On the other hand, the increase in students' ability to visualize the problem and check and evaluate the solution is in the moderate category. The indicator of problem-solving ability that experienced the highest growth was planning a solution, while the lowest increase occurred in the indicator of visualizing the problem.

Racking Analysis

The racking analysis technique is used to see changes in the difficulty level of items on the Static Fluids Problem Solving Test (SPRING) instrument, which is based on the logit value. A high logit value indicates that the item is difficult to complete, while a low logit value indicates that the item is easy to complete (Rosha et al., 2023). Changes in the difficulty level of the items can be seen through changes in the logit value or changes in the location of the items on the vertical ruler (Laliyo, 2021). Positive changes due to increased logit value illustrate that previously easy items have become difficult. The negative changes resulting from a decrease in the logit value illustrate that previously difficult items have become easy (Laliyo, 2021).

The following vertical ruler visualizes changes in the location of the difficulty level of the SPRING instrument items during the pretest and posttest.

The distribution of the difficulty level of the SPRING instrument items during the pretest and posttest is listed in the second column on the right. After the item number, Code A encodes the item's difficulty level at the pretest, while Code B encodes the item's difficulty level at the posttest. For example, code S1A indicates the difficulty level of item number 1 during the pretest. Based on Figure 3, all items on the SPRING instrument experienced a decrease in difficulty after the intervention. In line with the statement of Laliyo et al. (2022), the reduction in the level of difficulty of the items indicates that the ECIRR (Elicit, Confront, Identify, Resolve, Reinforce) model has a real influence on physics learning on static fluid material.



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|Measr|+Siswa   |-Indika|-Soal      |Scale|
|-----+---------+-------+-----------+-----|
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|     |         |       |           |     |
|     |         |       |           |  2  |
|     | *       | *     |           |     |
|   1 + ***     +       +           +     |
|     | ******  |       | S2A  S3A  | --- |
|     |         |       |           |     |
|     | ***     | *     |           |     |
*   0 * ****    * **    * S1A       *     *
|     | ******  |       |           |     |
|     | *       |       |           |     |
|     | **      |       |           |     |
|  -1 + ***     +       + S3B       +  1  |
|     |         |       |           |     |
|     | **      | *     |           |     |
|     |         |       |           |     |
|  -2 +         +       + S2B       +     |
|     | *       |       |           |     |
|     |         |       |           |     |
|     |         |       |           |     |
|  -3 +         +       + S1B       + (0) |
|-----+---------+-------+-----------+-----|
|Measr| * = 1   | * = 1 |-Soal      |Scale|
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Figure 3. Vertical Ruler of Changes SPRING Item Difficulty Level

Furthermore, the pattern of changes in the size of the item difficulty level during the pretest and posttest is shown in Table 4 below.

Table 4. Measure of Change in Item Difficulty Level SPRING

Item	Measure Logit		Diff.	Category
	Pretest	Posttest		
1	-0.09	-2.89	-2.80	Negative
2	0.84	-2.00	-2.84	Negative
3	0.86	-1.02	-1.88	Negative
Mean	0.54	-1.97	-2.51	Negative

The average difficulty level of the items at the pretest was 0.54 on the logit scale. After learning the ECIRR (Elicit, Confront, Identify, Resolve, Reinforce) model with a metacognitive approach, the average value decreased by -2.51 logits, from 0.54 to -1.97 logits. The decrease in the average logit value indicates that applying the ECIRR learning model with a metacognitive approach significantly impacts learning, so the items initially considered difficult by students become easy (Laliyo et al., 2022; Rosha et al., 2023). The difference in the pre-posttest logit values of the three items is more than -0.5, so the decrease is more significant (Hamdu et al., 2023).

CONCLUSION

Based on the pretest-posttest results analyzed using the stacking technique, implementing the ECIRR model with a metacognitive approach can improve students' problem-solving skills on static fluid material. The ECIRR model can help students integrate their knowledge and experience, while the metacognitive approach can help students understand their thinking process. Combining the ECIRR learning model with a metacognitive approach helps students optimize their learning potential. Analysis of the racking technique shows that the SPRING instrument can be used to identify students' problem-solving skills and significantly influence the learning process.

This study can be strengthened by using a control class to compare the results obtained in the control and experimental groups so that the effectiveness of the intervention can be determined objectively. Regarding learning activities, in the "resolve" section of the ECIRR model, learning activities focus on helping students overcome cognitive conflicts through real-world laboratory experiments. However, if students are unfamiliar with conducting experiments, teachers should provide specific guidelines and explanations for using the necessary tools beforehand.

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