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EXPRESSION-BASED E-WORKSHEET (EBEW): AN EFFORT TO ENHANCE STUDENT' COMPUTATIONAL THINKING SKILLS

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Abstract

Nowadays, physics learning in the classroom should no longer only focus on achieving academics. It must prepare students to face challenges in the future. One of the abilities that are important for learners is problem solving, and the problem-solving ability that is becoming increasingly important in today's digital era is computational thinking skills. Although computational thinking skills can be developed through worksheets, their integration into learning practices remains suboptimal. This study examines the effects of the ExPRession-based E-Worksheet (EBEW) on enhancing students' computational thinking skills in physics education. A quantitative approach with a pre-test and post-test quasi-experimental design was employed, involving 59 students divided into two groups. The control group participated in a simple laboratory practicum using discovery learning-based worksheets, while the experiment group engaged in a practicum facilitated by EBEW. Both groups completed a pre-test prior to the learning sessions. Results suggest that students using EBEW showed significantly deeper CT skills as compared to those using discovery learning-based worksheets. EBEW's structured learning phases, involving deep problem understanding, root cause analysis, predictive solution modeling, investigative procedures, and conclusion synthesis, effectively aided students in enhancing CT and problem-solving skills. These findings then suggest that EBEW not only enhances student learning on direct current circuit topics but also provides a readily extensible scaffold for broader STEM activities. This study underlines that EBEW has the potential to revolutionize physics learning with computational thinking by systemic processes of problem-solving. The present research was specifically directed toward DC circuits topic. However, the principles of EBEW are potentially applicable to other areas in physics for extended training in skills related to CT and to the reform of STEM education.

Keywords – Computational thinking skills, E-worksheet, ExPRession learning model, Physics learning.

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1. Introduction

The era of increasingly sophisticated and complex developments requires teachers to not only focus on teaching physics material content but also develop the skills needed by students in facing the challenges of an increasingly complex world (González-Pérez & Ramírez-Montoya, 2022; Rakowska & de Juana-Espinosa, 2021; Sihag & Sangwan, 2020; Walton, , Wilson, Murphy & Buchholz, 2022). It relates to the paradigm shift of education, which is now more oriented toward developing 21st-century skills. 21st-century skills are essential to prepare learners for the increasingly complex and changing world of work and life (McGunagle & Zizka, 2020; Meyer & Norman, 2020; van Laar, van Deursen, van Dijk & de Haan, 2020b; Vista, 2020). These skills include critical thinking, collaboration, creativity, communication, problem-solving, and digital literacy skills (González-Salamanca, Agudelo & Salinas, 2020; Lavi, Tal & Dori, 2021; St. Louis, Thompson, Sulak, Harvill & Moore, 2021; van Laar, van Deursen, van Dijk, & de Haan, 2020a).

Problem-solving ability refers to the ability to identify problems, analyze situations, evaluate options, and choose the best solution to achieve the desired goal (Akben, 2020; Eppe, Gumbsch, Kerzel, Nguyen, Butz & Wermter, 2022; Rizqa, Harjono & Wahyudi, 2020). This ability is essential for students because it can help them deal with complex situations in everyday life, at work, and in the learning process (Abdurrahman, Maulina, Nurulsari, Sukamto, Umam & Mulyana, 2022; Md, 2019; Nam, Hau, Thi & Tien, 2023; Tan, 2021). The ability to solve problems enables students to solve the problems they find. The more often they are trained when they are in school days, the more proficient they are in using it in everyday life (Hollenstein, Thurnheer & Vogt, 2022; Işiklar & Abali-Öztürk, 2022).

A kind of problem-solving ability, which, in today's world, especially amidst this digital age, shall be considered increasingly crucial, is computational thinking skills. Computational thinking skills in solving problems about algorithms, data structures, programming, logical thinking (Bers, Strawhacker & Sullivan, 2022; Saritepeci, 2022; Tsai, Liang, Lee & Hsu, 2022; Ung, Labadin & Mohamad, 2022), and some more comprise the subject area. Additionally, in general, computational thinking also has crucial implications for a learner's future career advance. This makes it imperative in practice to employ computational thinking across various working areas: technology, finance, science, and such, with an increase in efficiency and productivity along with the creation of truly creative and innovative solutions of complex problems (Amri, Budiyanto, Fenyvesi, Yuana & Widiastuti, 2022; Jeffrey, Lundy, Coffey, McBreen, Martin-Carrillo & Hanlon, 2022; Kafai & Proctor, 2022). Therefore, physics teachers should include computational thinking in physics learning to give the learners an opportunity to develop these skills for facing future challenges in improving themselves as competitive persons within the digital era.

Computational thinking will be helpful in dealing with complex problems related to the studies of physics. In particular, students with high computational thinking can create solution innovations from complex physics problems (Handayani, Prastowo, Prihandono, Nuraini, Supriadi, Maryani et al., 2022; Tofel-Grehl, Searle & Ball, 2022; Zakwandi & Istiyono, 2023). For example, direct current electric circuit material - this material requires abstract thinking in studying physical objects which are not visible to the eye. Most students have difficulty interpreting how electric current flows in a circuit (Zuza, Sarriugarte, Ametller, Heron & Guisasola, 2020) and solving problems related to a series of obstacles complex (Husnaini & Chen, 2019). Good computational thinking skills will help students explain the problems they find into representations that they better understand (Matsumoto & Cao, 2017), break down complex problems into more straightforward problems, and decide on steps in solving these problems (Pratiwi, Herlina, Viyanti & Andra, 2023; Oluk & Çakir, 2021; Rijke, Bollen, Eysink & Tolboom, 2018). It will help get rid of the difficulties students have in comprehending direct current electric circuit material.

Therefore, educators need to make efforts to be able to develop students' computational thinking skills. Teachers can create learning environments that train computational thinking skills by facilitating students' collaboration, providing access to a variety of media or resources that supports learning, and encouraging students to use digital applications to find information, discuss, collect, and process data to solve problems (Pou, Canaleta & Fonseca, 2022; Seitan & Aljarrah, 2021). This learning implementation aligns with Siemens' (2005) connectivist learning theory, which states that learning occurs through direct experience and networks or connections between various resources, such as people, technology, and information (Gr. Voskoglou, 2022; Yu, 2021). In addition, teachers can also practice computational thinking skills by connecting new knowledge with students' knowledge in building a more meaningful understanding of the topics studied (Fernández-Ferrer & Espinoza-Pizarro, 2022; Lins, Coelho, Lins, Gomes, Melo, & Coelho, 2020). Students redescribe their understanding in a form that is easier for them to understand (Andrian & Hikmawan, 2021; de Melo & Melo, 2021; Handayani et al., 2022). It pertains to the implementation of meaningful learning, which transpires when learners can integrate new knowledge with prior knowledge to construct a coherent cognitive framework (Ausubel & Fitzgerald, 1961). Teachers can also prepare worksheets to involve learners in problem-solving steps (Muliyati, Sumardani, Siswoyo, Bakri, Permana, Handoko et al., 2021; Uzel & Bilici, 2022). In physics learning, worksheets can be used to provide tasks that demand computational thinking skills, such as visualizing data, creating models or simulations, and analyzing experiment or observation results (Chevalier, Giang, El-Hamamsy, Bonnet, Papaspyros, Pellet et al., 2022; Jung, Choi & Park, 2022; Prommun, Kantathanawat, Pimdee & Sukkamart, 2022).

In line with the principles of connectivity learning theory and meaningful learning, the ExPRession (External Physics Representation) learning model contains activities to train students to observe occurring phenomena and relate the information obtained to their initial understanding. Students also make various representations of problems to help build mental models that will later impact students' problem-solving abilities in solving ill-structured and well-structured problems (Herlina, 2022). This learning model has five stages: orientation, expression, investigation, evaluation, and generalization (Herlina, 2022). Applying this learning model positively impacted numeracy ability (Sri-Haryanti, Herlina & Abdurrahman, 2023) and problem-solving skills (Herlina, Widodo, Nur & Agustini, 2016).

Although computational thinking skills are essential for physics learning and can be trained through the use of worksheets, computational thinking skills have not been optimally developed in learning (Angeli & Giannakos, 2020; Montiel & Gomez-Zermeño, 2021). It is reinforced by preliminary research conducted by researchers, which shows that physics learning in the classroom has not trained learners to use their computational thinking skills to integrate ideas, data, and logic to find solutions, so they have difficulty in using the right formulation/formula to be used in each problem contained in the problem (Pratiwi et al., 2023). In addition, ExPRession has not been widely applied in physics learning (Pratiwi et al., 2023, Herlina, 2022; Herlina et al., 2016; Sri-Haryanti et al., 2023). ExPRession has the potential to be applied in direct current circuit learning units to stimulate computational thinking skills. Students can analyze phenomena, formulate problems based on observations, translate problems into various forms of representation, test hypotheses, have discussions, evaluate, and solve problems using physics approaches, specific applications of physics, mathematical procedures, logical progression, and functional description abilities with the help of ExPRession pedagogy (Pratiwi et al., 2023; Herlina, 2022). This research has developed e-worksheets that apply ExPRession on DC circuits material, providing opportunities for students to solve problem systemically to enhance computational thinking skils.

2. Research Method

This current study is a continuation of the development research carried out by researchers where an ExPRession-based E-Worksheet (EBEW) has been produced (Pratiwi et al., 2023), designed to stimulate computational thinking skills. Based on the results of expert tests, EBEW has good validity and practicality, so that it can be used in physics learning. The sample of this current study was 59 students in Lampung Province, Indonesia. The students came from 2 classes; the first was the control class (n = 27), and the second was the experimental class (n = 32). The reason for choosing the two classes is to be taught by the same physics teacher. Table 1 shows the details of the samples and environment.

Class	Number of Students	Environment
Control	27	Classic Laboratory with Discovery Learning
Experiment	32	EBEW Assisted Laboratory

Table 1. Symbolic representation of the sample and environment

Students in the control class learn about direct current electric circuits with a learning environment in the form of a simple practicum in the laboratory with the help of worksheets with a discovery learning model. At the same time, the experimental class will conduct learning in a learning environment in the form of a practicum guided by EBEW. This study aimed to compare computational thinking skills in both learning environments.

This current study was quantitative research with a pre-test and post-test quasi-experimental design. The dependent variable of the research is computational thinking skills, and the independent variable is the learning environment. Both classes will do a pre-test before learning. Then both classes conduct learning according to a predetermined learning environment. After the lesson is done, both classes do the post-test. Figure 1 shows the research procedure.

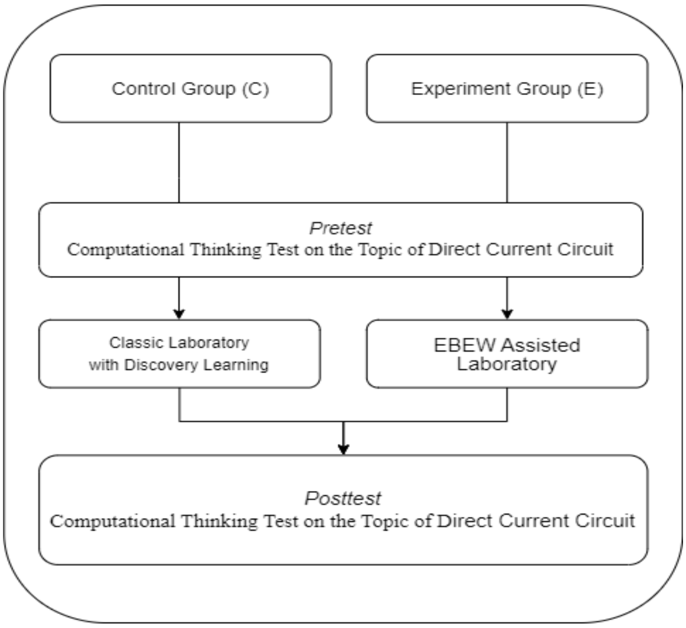


Figure 1. Research Procedure

The instruments used are pre-test and post-test questions on direct current electric circuits. The problem consists of 5 sub-topics: the units in direct electric current, Ohm's Law, electrical resistance, series of resistance, and Kirchhoff's Law. Each sub-topic is made according to indicators of computational thinking skills presented by Wing (2006): Abstraction, Algorithms, and Generalization. The test was then tested for the validity of its contents by a physics education lecturer and a physics teacher. It led to a specific change in the test. Next, the test was tested on 26 students. This pilot test was carried out to determine the reliability of the question items. The pilot test results showed a Spearman-Brown reliability coefficient of .87, so this problem can be used in research.

The One Sample Kolgomorov Smirnov test was used to analyze the data and perform a normality test on the pre-test and post-test scores. The data of asymp. Sig for pre-test and post-test on control class are .20 and .14. Those are greater than .05 level of significance. So that, pre-test and post-test scores on control class is distributed normally. Next, the data of asymp. Sig for pre-test and post-test on experiment class are .098 and .18. Data that has been tested for normality will be tested with parametric statistics. Each group's pre-test and post-test scores were compared using a dependent t-test, and the groups were compared using an analysis of variance (ANOVA). To find out how much the use of EBEW affected computational thinking abilities, effect size tests were also carried out.

3. Results and Discussion

The results of the dependent t-test showed that both learning environments had a positive impact on computational thinking skills. For control class, the value of t is 11.45, more significant than the t table: 1.71 for df: 26 and .05 levels of significance. These results significantly differ from control group's average pre-test and post-test. Meanwhile, for experiment group, the value of t is 29.36, more significant than t table: 1.70 for df: 26 and .05 levels of significance. These results also significantly differ in experiment class's average pre-test and post-test.

Class	Data	N	$\bar{X}$	SD	t
Control	Pre-test	27	41.61	11.45	12.47
	Post-test	27	66.79	7.59	
Experiment	Pre-test	32	42.50	6.93	29.36
	Post-test	32	81.46	7.52	

Table 2. Results of t-test for students' pre-test and post-test scores

Based on the analysis of variance (ANOVA), the F value is 55.20, more significant than the F value of the table: 4.01 for the .05 level of significance. It showed that there is a difference in the average computational thinking skills between the control class and the experimental class. Researchers also found that the effect size was .55 with the moderate category. It showed that using EBEW in learning impacts students' computational thinking skills.

Based on the interviews conducted after the learning process, students in control group felt happy with the use of worksheets with discovery learning because they are guided to understand the concept of Direct current electrical circuits through activities on worksheets. It is just that when they do the post-test, they find it challenging to answer the questions given. They were used to answer questions directly without using systematic methods. Nevertheless, they tried their best to answer the post-test questions. Meanwhile, students in experiment group found it helpful to use EBEW. Not only to understand the concept but also when answering Post-test questions. Each stage in EBEW helped them use their computational thinking skills and got used to solving problems systematically so that when doing problems, they did not find it difficult. It was conveyed by Andrian and Hikmawan (2021), and Maharani, Kholid, Pradana and Nusantara (2019) that computational thinking skills could be trained with activities that made students solve problems systematically.

Learning with EBEW followed the ExPRession learning steps: Orientation, Expression, Investigation, Evaluation, and Generalization as shown in Figure 2. In the Orientation stage, students observed the phenomenon (ill-structured problem) presented in EBEW. Then they gathered information from various sources to make predictions and answered questions available in EBEW. This activity trained Problem Decomposition skills, where they observed the phenomena presented, arranged phenomena into more straightforward problems, and then look for relevant information to answer the questions and solved the problem well. The phenomena were presented through several videos embedded in EBEW, covering topics such as electrical installations in residential settings, visualizations of electric current flow, illustrations of the differences between open and closed circuits, and comparisons between series and parallel circuits. Figure 3 displays one of these videos along with students' responses, where they predicted the flow of electric current through conductor wires and identified the type of charge involved. Based on the figure, students predicted that the electric current is caused by the flow of both electrons and protons, which is partially incorrect. These activities align with Rijke et al. (2018), who state that the ability to decompose problems is a computational thinking skill that helps students break down complex problems into smaller components, identify the root cause, and determine the most effective solution.

Figure 2. ExPression learning stages

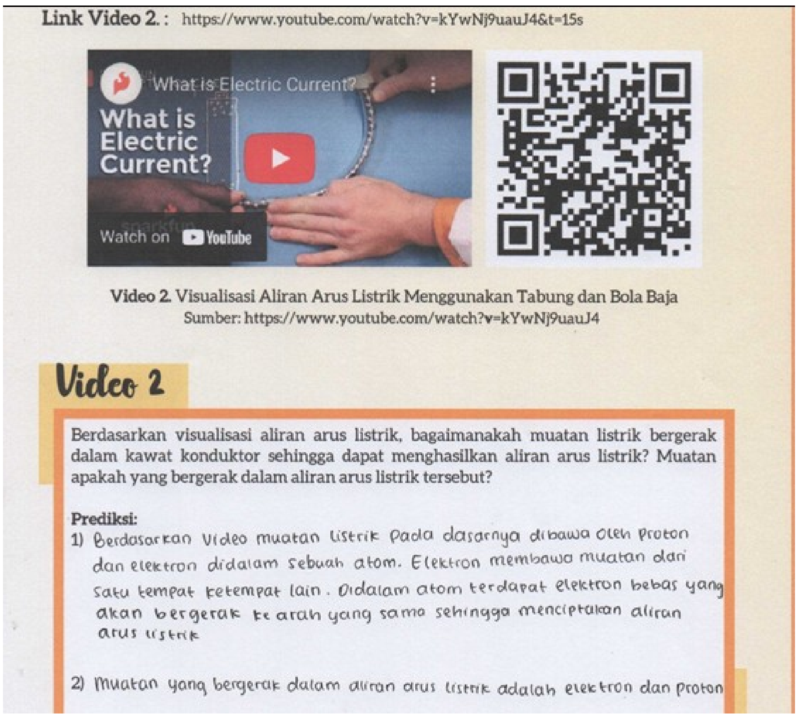


Figure 3. Student's ideas about the problem from the video

Furthermore, in the Expression stage, students were asked to describe the main problem they will solve, make sketches/drawings representing it, and make physical representations into mathematical equations. At this stage, teachers stimulated abstraction skills by asking students to sketch out the problems they have determined in the previous stage. One example is that students were asked to sketch electrical installations commonly found at home, as shown in Figure 4. The sketch reflects the students' understanding of electric circuits, particularly the parallel circuits typically used in house settings. Abstraction is indeed shown by the ability of students to re-describe their understanding in a form that is easier for them to understand (Andrian & Hikmawan, 2021; de Melo & Melo, 2021; Handayani et al., 2022). Meanwhile, at this stage, students were also asked to make mathematical equations related to the understanding. One of them is that students were asked to make an equation for the electric current. This activity trained students' generalization skills, where students model their understanding into mathematical equations (de Melo & Melo, 2021; Matsumoto & Cao, 2017).

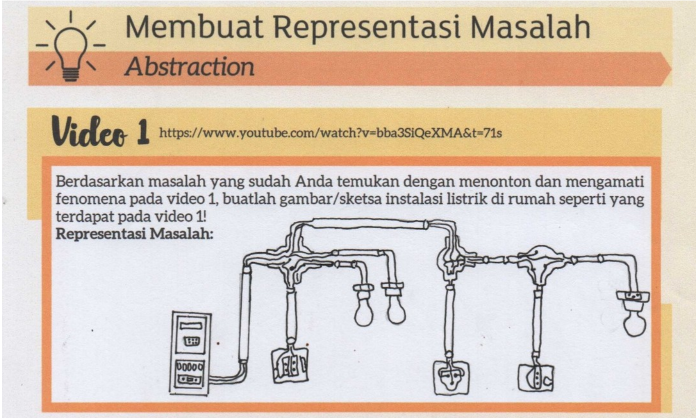


Figure 4. Student's sketch about electrical installation

At the investigation stage, students were trained in algorithms skills by making problem formulations, hypotheses, and steps they will take to test their hypotheses. As shown in Figure 5, students generated hypotheses relevant to the problem being addressed, demonstrating their ability to generate appropriate assumptions. Figure 5 illustrates the students' answers are in good agreement with accepted theoretical ideas about electric current. Their presumptions show a thorough comprehension of the fundamentals of electricity, including the relationship between current, voltage, and resistance in both series and parallel circuits.

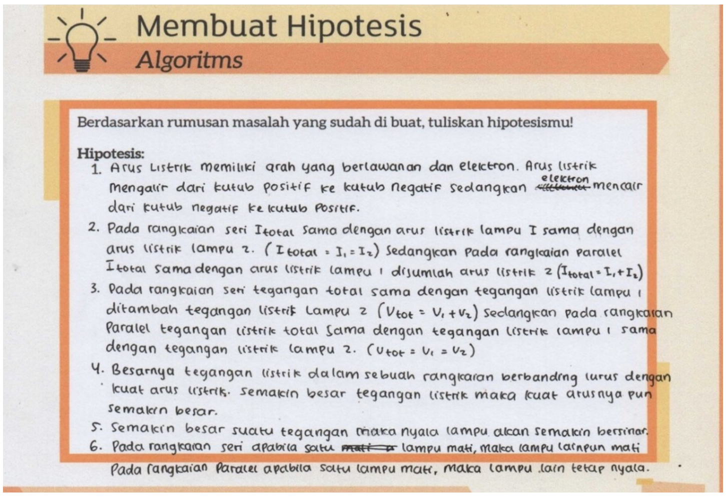
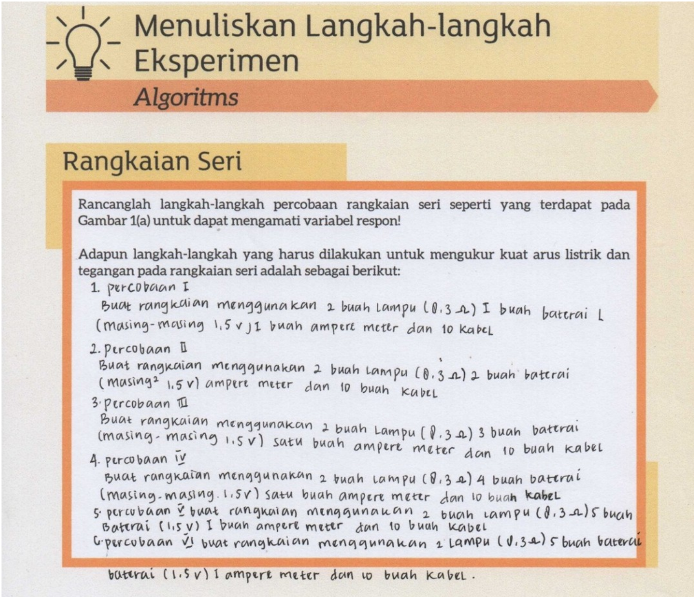


Figure 5. Student's Hypotheses

Moreover, Figure 6 depicts the steps students proposed to test their hypotheses, highlighting their algorithmic skills in designing experimental procedures. The proposed steps involve varying the voltage and measuring its effect on the electric current, which are appropriate for addressing the problem statements. This aligns with the findings of Güler (2021) and Oluk and Çakir (2021), which suggest that algorithmic capabilities emerge when learners are tasked with creating systematic and concrete steps to solve problems. Furthermore, in the investigation stage, students also trained automation skills by collecting and processing the data into graphs by using a Spreadsheet, as shown in Figure 7. First, students collected data into a table, including resistance, voltage, and electric current in a closed circuit powered by 1 to 6 batteries. Next, they plotted a graph of electric current versus voltage. The use of data processing applications significantly aids students in understanding and solving questions or problems more effectively and efficiently (Dana-Picard, 2023; Ting, Talib, Ayub, Zolkepli Yee & Hoong, 2023). According to Juárez and Guzmán's (2022) research, spreadsheets help students process and interpret data while encouraging computational thinking. As part of the investigation process, students draw conclusions that reflect their generalization skills, demonstrating their ability to synthesize and summarize their learning experiences (de Melo & Melo, 2021; Matsumoto & Cao, 2017).



Menuliskan Langkah-langkah Eksperimen

Algoritms

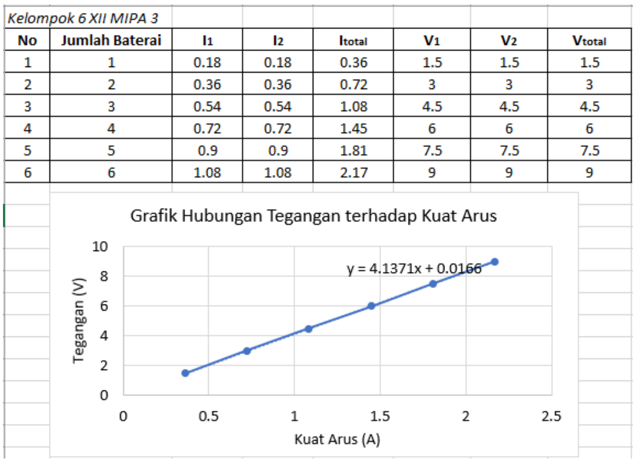
Rangkaian Seri

Rancanglah langkah-langkah percobaan rangkaian seri seperti yang terdapat pada Gambar 1(a) untuk dapat mengamati variabel respon!

Adapun langkah-langkah yang harus dilakukan untuk mengukur kuat arus listrik dan tegangan pada rangkaian seri adalah sebagai berikut:

1. percobaan I
   Buat rangkaian menggunakan 2 buah Lampu (0.3 Ω) I buah baterai L (masing-masing 1,5 v) I buah ampere meter dan 10 kabel
2. Percobaan II
   Buat rangkaian menggunakan 2 buah Lampu (0.3 Ω) 2 buah baterai (masing² 1.5 v) ampere meter dan 10 buah kabel
3. Percobaan III
   Buat rangkaian menggunakan 2 buah Lampu (0.3 Ω) 3 buah baterai (masing-masing 1.5 v) satu buah ampere meter dan 10 buah kabel
4. percobaan IV
   Buat rangkaian menggunakan 2 buah Lampu (0.3 Ω) 4 buah baterai (masing-masing. 1.5v) satu buah ampere meter dan 10 buah kabel
5. percobaan V buat rangkaian menggunakan 2 buah Lampu (0.3 Ω) 5 buah Baterai (1.5 v) I buah ampere meter dan 10 buah kabel
6. percobaan VI buat rangkaian menggunakan 2 Lampu (0.3 Ω) 5 buah baterai baterai (1.5 v) 1 ampere meter dan 10 buah kabel.

Figure 6. Steps to test the hypotheses



Kelompok 6 XII MIPA 3

No	Jumlah Baterai	I1	I2	Itotal	V1	V2	Vtotal
1	1	0.18	0.18	0.36	1.5	1.5	1.5
2	2	0.36	0.36	0.72	3	3	3
3	3	0.54	0.54	1.08	4.5	4.5	4.5
4	4	0.72	0.72	1.45	6	6	6
5	5	0.9	0.9	1.81	7.5	7.5	7.5
6	6	1.08	1.08	2.17	9	9	9

Figure 7. The students used the spreadsheet to process data

For the evaluation stage, students presented the investigation results and provided feedback on each other's presentations. This activity is carried out to provide meaning to learning. The hope is that by giving each other input on their presentations, students will be able to assess the learning they do so that they can improve future learning (Flores, Zubiría & Sebire, 2022). As the last stage, the Generalization stage in EBEW required students to applying learned-problem solving to different context by employing a comprehensive and systematic problem-solving approach (Pratiwi et al., 2023; Herlina, 2022). This stage was designed to facilitate problem-solving by guiding students through formulating problems, developing hypotheses, identifying variables, and addressing real-world issues (Herlina, 2022). By engaging in these activities, students were able to develop and practice key indicators of computational thinking skills. This is consistent with research by Muliyati et al. (2021), which shows that scaffolded worksheets help students build generalization abilities by enabling them to adapt problem-solving techniques to a greater variety of situations and obstacles.

However, the implementation of the ExPRession learning model, especially at the expression stage, may provide potential obstacles for students. During the expression stage, students are tasked with describing problems, making sketches, and translating physical phenomena into mathematical equations. Challenges arise since these tasks require strong visual capability and systematic thinking; hence, students with poorly developed visual-spatial skills or weak foundational knowledge may experience difficulties. This is corroborated by Bradley, Allred and Zeidan (2019) and Herlina, Nur and Widodo (2017). Additionally, linking abstract concepts with their mathematical representations is generally overwhelming for learners, as indicated by Rangkuti (2023). To surmount this challenge, it is essential to use scaffolding guidance, demonstration, and practice.

Another issue that students face in their learning, apart from what is mentioned above, is the problem that requires an internet access, since most e-worksheets are actually Heyzine-based assignments, some YouTube videos that, even though schools do have access to through Wi-Fi, still students cannot have enough with this. The internet problem in ICT-based teaching and learning has been mentioned in several previous studies, among others, by Almelhes (2021), Linhais and da Silva (2023), and Suana (2018). Thus, for successful implementation in schools, educators must ensure that sufficient internet access is available for the learning process.

This research indicates that the ExPRession learning model, which is implemented by e-worksheets, increases students' computational thinking in physics classes in a direct current electric circuit. Every phase within this model is done in such a systematic way to take the students to problem identification, creation of representation, formulation of hypothesis, problem-solving steps design, data collection and analysis, and evaluation and generalization. This structured approach will not only encourage active learning but also provide students with fundamental competencies of the 21st century, such as data analysis skills, which can be further enhanced by using tools like spreadsheets.

Educators may include the ExPRession learning model in lesson plans, accompanied by appropriate worksheets. This gives a useful framework through which to teach and reinforce CT skills in physics, affording students the chance to engage in meaningful systematic problem-solving activities. By building these practices into regular instruction, teachers can develop students' skills in problem decomposition, abstraction, algorithms, automation, and generalization. This better prepares them to face the challenges of an ever-changing world that is steeped in technology.

4. Conclusion

This study demonstrated that the students who learned by using EBEW have better computational thinking skills than those using worksheets based on discovery learning. Besides, the learning environment actively engages students in the process of learning, which improves problem-solving performance and thus has had a positive effect on computational thinking skills. Moreover, EBEW supported students in understanding problems more deeply, identifying their root causes, predicting solutions, conducting investigations, and drawing conclusions. These steps systematically trained the students in problem-solving and greatly enhanced their computational thinking skills. Therefore, EBEW is a useful approach for fostering computational thinking skills in physics learning through systematic problem-solving.

Although these results really showcase how the EBEW method enhances computational thinking skills in students in this particular learning of direct current electric circuits, there are hints that it may work equally well on other physics topics which are abstractly similar-like static electricity, magnetism, optics, and modern physics. However, further investigation into the research patterns over longer terms-such as by conducting a longitudinal study-may still be required. In this regard, exploring the implications of EBEW in general broader areas of STEM might allow better application of this notion. Such a study would generalize these findings, extend the potential benefits of the method, and establish the position of computational thinking as an important skill in the era of fast development in the 21st century.

Declaration of Conflicting Interests

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