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Developing Programming Learning Media Using Scratch on the Concept of Buoyancy to Improve Computational Thinking in Primary School

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ABSTRACT
The research focuses on the development of educational media using Scratch, a visual programming platform, to teach the concept of buoyancy and enhance computational thinking (CT) skills in primary school students. By adopting the 4D development model (Define, Design, Development, Dissemination), the study identifies challenges in traditional teaching methods, particularly the abstract nature of buoyancy, which often leaves students unengaged. The Scratch-based media addresses this by providing interactive simulations, allowing students to visualize and experiment with floating and sinking objects, thus making the learning process more engaging. The study involves designing a storyboard and flow of the media, followed by the development of simulations where students instruct sprites (characters) to test buoyancy. The media's effectiveness is validated by experts, who rate it based on display design, navigation, content relevance, interactivity, and technical suitability, with the overall results indicating that the media is valid and practical for use in educational settings. This approach not only helps students grasp scientific concepts but also builds their CT skills by integrating programming with science learning. The findings imply that such interdisciplinary tools can transform science learning by making abstract concepts more accessible and engaging, and encourage the development of both scientific and computational competencies in young learners.

Keywords: *buoyancy; computational thinking (ct); educational media; primary education; scratch programming*

INTRODUCTION

In this era of globalization and rapid technological development, Science, Technology, Engineering, and Mathematics (STEM) education is becoming increasingly crucial, especially at the primary school level (Hudson et al., 2015). As stated by Baharin et al. (2018), STEM education not only aims to provide basic knowledge in science and technology but also to equip students with critical, creative, and analytical thinking skills necessary to face future challenges (Ah-Namand & Osman, 2018). The implementation of STEM education in primary schools plays an important role in building a strong foundation for students (Chiu et al., 2015). At this age, students have a high level of curiosity and the ability to absorb knowledge quickly (Engel, 2015; Scott-Barrett et al., 2023). Therefore, integrating STEM into the basic curriculum can increase students' interest and motivation towards science and technology from an early age (Gresnigt et al., 2014). In addition, it not only encourages students to understand and apply scientific concepts in real-world contexts, but also prepares them for career possibilities and future life (Hanif et al., 2020).

Talking about higher order of thinking skills in the 21st century, computational thinking is one of the most essential skills (Grover & Pea, 2013). It is an approach to problem-solving that involves systematic and logical thinking processes, often used in computer science (Cansu & Cansu, 2019). This concept encompasses several key skills, such as decomposition, pattern recognition, abstraction, and algorithm design (Kalelioglu et al., 2016). Decomposition involves breaking down complex problems into smaller, more manageable parts (Rich et al., 2019). Pattern recognition helps in finding similarities and differences in data or problems (Kalelioglu et al., 2016). Abstraction involves simplifying problems by focusing only on important information, while algorithm design involves creating clear steps or instructions to solve problems (Grover & Pea, 2013). Thus, computational thinking enables students to approach problems in a more structured and efficient manner.

The importance of developing computational thinking skills from an early age cannot be overlooked. In an increasingly digital and technology-based world, the ability to think computationally helps students not only in science and technology subjects but also in various aspects of daily life (Chalmers, 2018). By mastering these skills, students can solve problems systematically and logically, reducing complexity and increasing efficiency in finding solutions (Wan et al., 2021). Also, computational thinking also helps students develop critical and analytical thinking skills, which are essential in facing both academic and real-life challenges (Hanif et al., 2020). Teaching computational thinking to primary school children provides them with useful tools to become better and more innovative thinkers in the future.

Scratch is a visual programming learning platform developed by the MIT Media Lab. Designed specifically for children and beginners, Scratch offers a user-friendly and intuitive approach to learning coding (Romero & Artal-Sevil, 2021). It features a colorful and engaging graphical interface with code blocks that can be assembled like puzzle pieces. As claimed by Fagerlund et al. (2021), this approach eliminates the intimidation often associated with traditional programming languages, making it highly suitable for children.

Despite its simplicity, Scratch is capable of teaching fundamental programming concepts such as loops, conditionals, variables, and functions (Olabe et al., 2011). Satria et al. (2024) stated that children can learn these concepts while creating fun interactive projects like animations, games, and interactive stories, fostering creativity alongside coding skills. Available for free and accessible through web browsers, Scratch is easily used both at school and at home. Therefore with these features, Scratch becomes a highly effective tool for introducing children to the world of programming, building a strong foundation for further coding education in the future.

Combining science learning with programming can create a highly valuable and interdisciplinary learning experience for students (Carter, 2014). According to Fagerlund et al. (2021), this integration enables students to not only learn about scientific phenomena but also how to use technology to model, analyze, and visualize these concepts. For example, through the use of platforms like Scratch, students can create interactive simulations depicting ecosystems by manipulating variables such as predator populations or food availability, and observe how these changes affect the ecosystem's balance. This process not only enhances their understanding of ecology but also teaches them about mathematical modeling and programming logic (Funke et al., 2017; Satria et al., 2024). Thus, this integration helps prepare students for the real world where technology and science often go hand in hand (Rehmat & Bailey, 2014).

Furthermore, the integration of science and programming through platforms like Scratch can increase student motivation and engagement (Dúo-Terrón, 2023). The ability to create interactive and visual projects makes science learning more interesting and relevant to students. It also opens up opportunities for creativity and self-expression, as students can design their own projects that combine their personal interests with the scientific concepts being studied (Kalelioglu & Gülbahar, 2014; Kobsiripat, 2015). As a result, combining science learning with programming, especially through platforms like Scratch, can provide a rich and multi-dimensional learning experience (Funke et al., 2017; Satria et al., 2024).

Research indicates that Scratch-based programming instruction can significantly improve various cognitive abilities in young learners. For example, Sáez-López et al. (2016) and Rodríguez-Martínez et al. (2020) observed notable enhancements in primary students' problem-solving capabilities when using Scratch. Durak (2020) reported improvements in reflective thinking skills, while Jiang (2021) noted advancements in creative, cooperative, and critical thinking abilities. Beyond cognitive benefits, Scratch has been shown to positively impact students' learning experiences. Chou (2020) and Sáez-López et al. (2016) found that incorporating Scratch into programming education increased students' motivation to learn. Kong and Wang (2019) observed that students demonstrated better focus during lessons involving Scratch. Moreover, Pérez-Marín et al. (2020) reported that students found the learning process more enjoyable when using this platform. These findings collectively underscore Scratch's potential as a versatile educational tool that not only develops CT skills but also enhances overall engagement and enjoyment in the learning process.

Despite these encouraging results, there remains a significant research gap in the field. Most existing studies focus on using Scratch for general CT development or within computer science education. There is limited research on using Scratch to teach specific science concepts while simultaneously developing CT skills. For instance, the concept of buoyancy (floating and sinking), which is a fundamental topic in primary science curricula, has not been extensively explored in conjunction with Scratch-based learning. Thus, this study aims to address this gap by developing and evaluating custom programming learning media using Scratch, specifically designed to teach the concepts of floating and sinking while enhancing CT skills. By doing so, it seeks to provide valuable insights into how subject-specific Scratch applications can be effectively integrated into science education, potentially opening new avenues for interdisciplinary learning in primary schools.

METHODOLOGY

Because this study aims to develop educational media using Scratch, a visual programming platform, to teach the concept of buoyancy and enhance computational thinking (CT) skills in primary school students, the authors used Research and Development (R&D) design using the 4D development model (Define, Design, Development, Dissemination) as put forth by Gall et al. (1996). The R&D method is used to produce a product, in this example, an educational medium, which is then tested after the design and development phase to make sure it works as a practical teaching aid. The learning topic centers on the concepts of buoyancy, (floating and sinking), which is integrated into programming activities using Scratch to enhance students' computational thinking skills. The language used in the simulation is Indonesian, since it is intended for Indonesian-speaking primary school students. The stages of the 4D development model in this study are as follows:

Define Stage

During the define stage, a preliminary analysis is carried out to pinpoint the learning challenges that students face and to get feedback from educators and students on the current curriculum-aligned learning practices. In order to guarantee that the learning process goes as it should, the objective is to create planning solutions that will assist in determining the proper learning patterns for both teachers and pupils.

According to this study, teachers can give lessons on the notion of buoyancy more engagingly because of the development of educational media based on Scratch. The final product must also meet the needs of primary school students, who are in the concrete operational stage of development. This means that while they are able to reason logically, they can only apply reasoning to concrete things in order to solve issues. in addition, the study includes an analysis of the learning environment, revealing challenges related to time constraints in manually conducting STEM projects, particularly on the topic of buoyancy.

Design Stage

In this second stage, the media that students need is designed in order to address the needs that have been discovered. During this stage, a development team is formed. They designed the storyboard for the educational media created from scratch, taking into account the needs of the students for the content, graphics, and navigation. In addition, the researchers determined what resources are required, including hardware (computers and laptops), software (the Scratch program), internet connectivity, electrical power availability, and other resources that are critical to the development process. The researchers also drafted a development schedule, which spans from January to July 2024.

Development Stage

In the development stage, the educational media for the buoyancy concept is created using the Scratch application based on the pre-designed plans, and validation evaluations are conducted by media experts, material experts, and users (teachers and students). The development process consists of two main steps: creating the Question File and creating the Answer File.

Step 1: Creating Question Files

Open Scratch and create a new project named "Buoyancy Questions." Add the following sprites: Jake and James as guides who will provide instructions, an aquarium to serve as a water container for testing buoyancy, and an orange and a watermelon as objects to be tested in the water. Finally, add a background that includes a stage and the aquarium to complete the project setup.

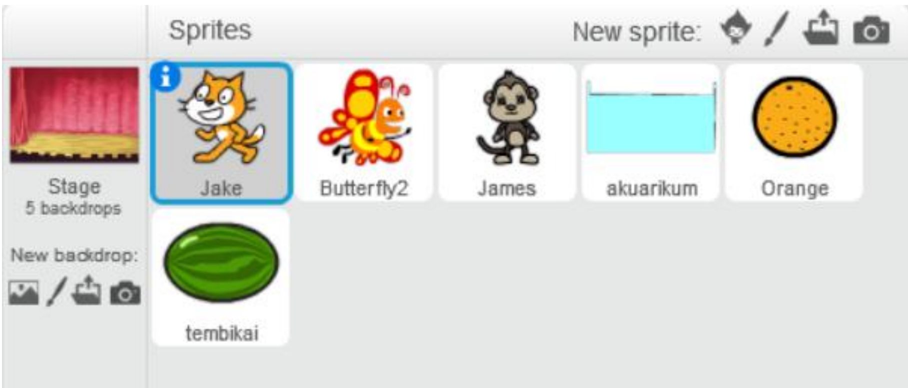


Figure 1. Adding Sprites

Jake Sprite: Add instruction blocks to the Jake sprite as shown in the figure.

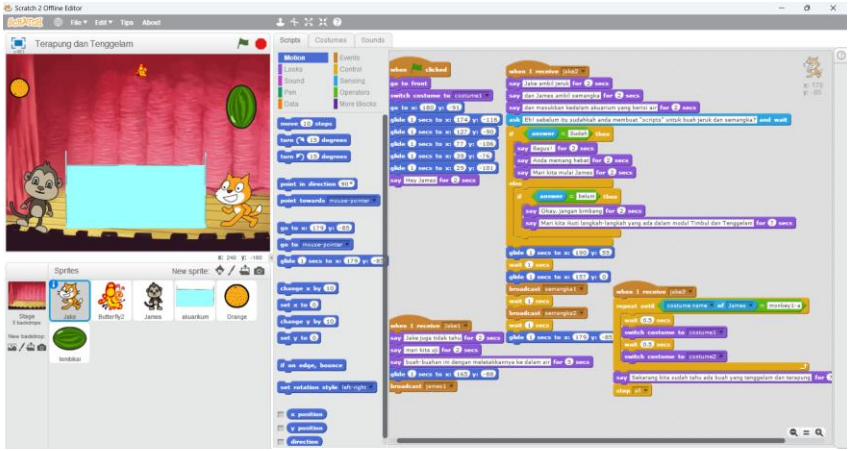


Figure 2. Programming character Jack

James Sprite: Add instruction blocks to the James sprite as shown in the figure.

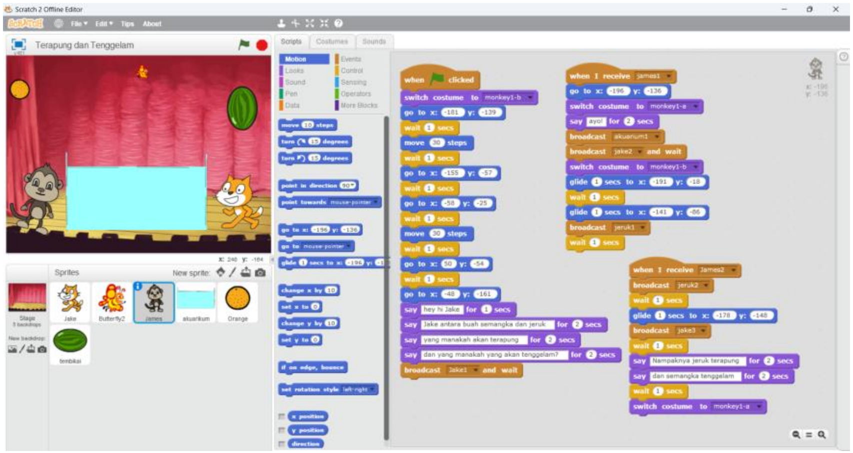


Figure 3. Programming character James

Orange Sprite: Add instruction blocks to the Orange sprite as shown in the figure.

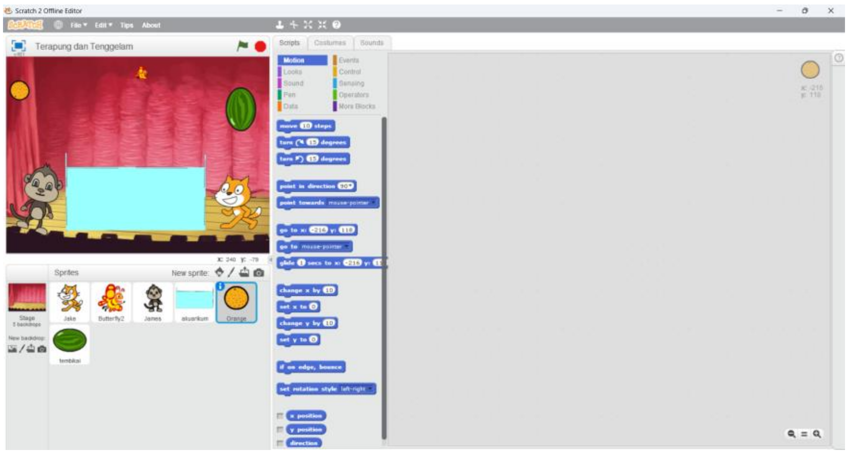


Figure 4. Programming sprite for Orange

Watermelon Sprite: Add instruction blocks to the Watermelon sprite as shown in the figure.

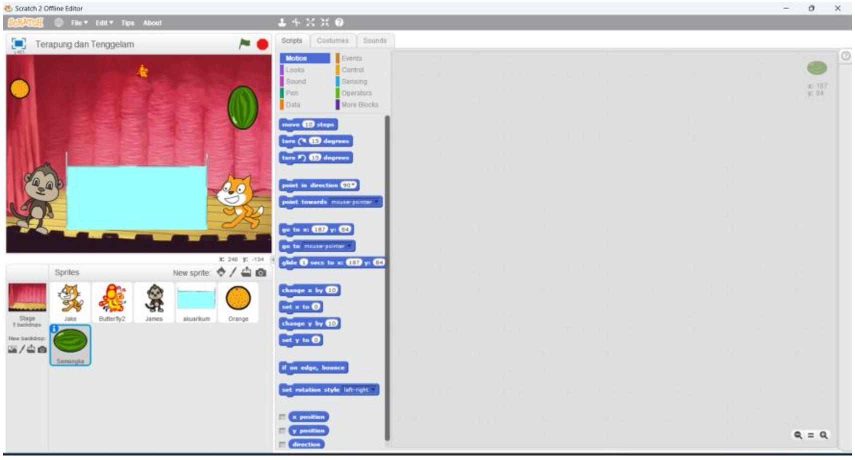


Figure 5. Programming sprite for Watermelon

Step 2: Creating Answer Files

Duplicate the question file and rename the project "Buoyancy (Floating and Sinking) Answers." Complete the unfinished instruction blocks in the question file by adding the correct logic. For the Jake sprite, ensure the instruction blocks are completed as illustrated in the provided figure.

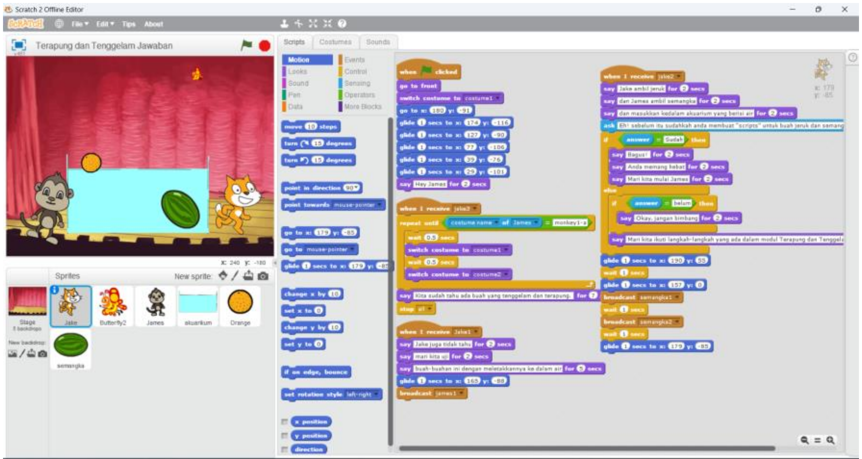


Figure 6. Instruction blocks for Jack sprite

James Sprite: Complete the instruction blocks for the James sprite as shown in the figure.

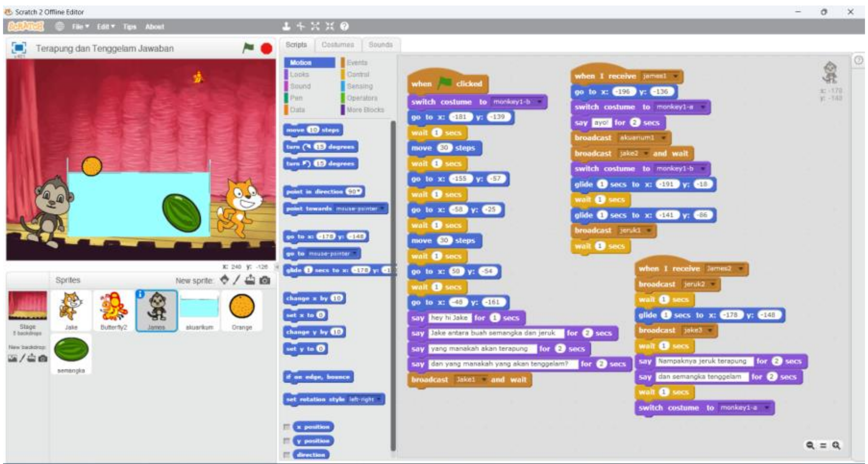


Figure 7. Instruction blocks for James sprite

Orange Sprite: Complete the instruction blocks for the Orange sprite as shown in the figure.

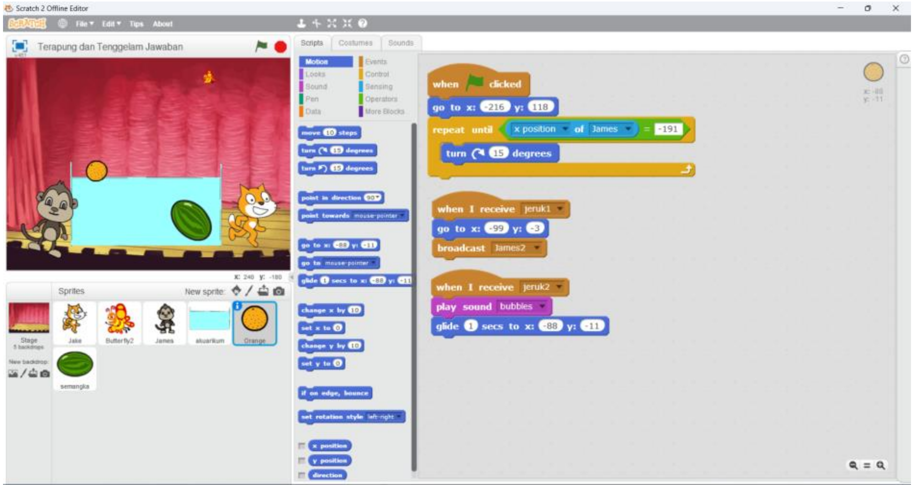


Figure 8. Instruction blocks for Orange sprite

Watermelon Sprite: Complete the instruction blocks for the Watermelon sprite as shown in the figure.

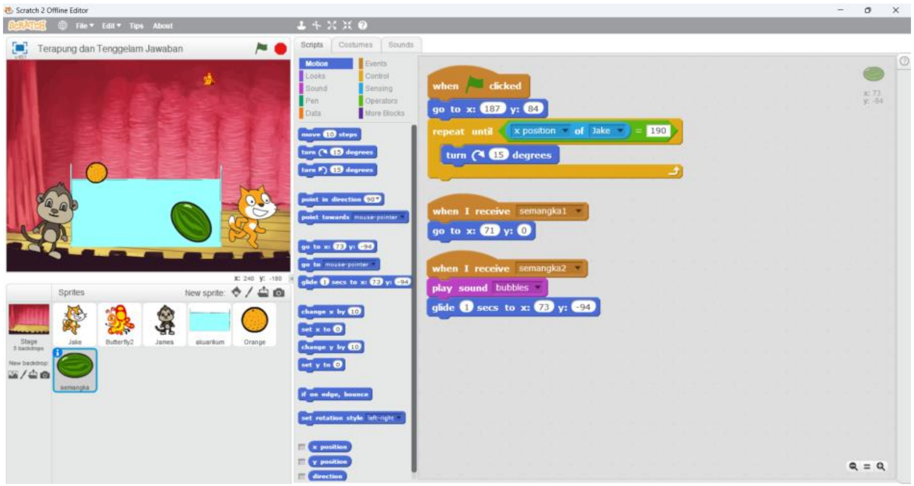


Figure 9. Instruction blocks for Watermelon sprite

Test the Answer: Run the project to ensure the provided solution actually works.

After the development of the media, the next step in this study is the testing phase of the educational media, which is conducted on a small scale with 10 elementary school students. This phase is intended to assess whether the media can be effectively used by the students and to gather their opinions on the Scratch media related to the buoyancy concept. The data collection instruments used in this study include expert validation sheets and practicality instruments. The validation instrument is developed according to the validation aspects outlined in Table 1.

Table 1. Validation indicators

No	Evaluation Aspect	Indicators
		Suitability of the design for the target audience
		Appropriateness of colors and fonts
1	Display Design	Consistency of design across screens
		Text readability and icon clarity
		Overall aesthetics

No	Evaluation Aspect	Indicators
2	Navigation	Ease of navigation
		Clarity of instructions
		Completeness of navigation buttons
		Responsiveness of buttons and features
3	Conformity Content	Relevance of content to learning objectives
		Alignment of material with the curriculum
		Accuracy of information
		Integration of content with interactive activities
4	Interactivity	User engagement level
		Creativity in content presentation
		Diversity of interactive activities
		User feedback from activities
5	Technical suitability	Compatibility with various devices
		Application stability
		Loading and response speed
		User data security

In addition to completing the instrument using a 1-4 Likert scale, the validators also provided suggestions and feedback for improving the Scratch media that they deemed inappropriate. The questions given in the instrument for assessing the practicality of using Scratch media can be seen in Table 2.

Table 2. Practicality instrument

No	Question
1	The Scratch-based learning media is easy to understand.
2	The instructions in the learning media are clear and easy to follow.
3	I feel happy when using this learning media.
4	This learning media helps me understand the concept of buoyancy well.
5	I can follow the programming steps in Scratch without difficulty.
6	This learning media is interesting and makes me more interested in learning programming.
7	This learning media motivates me to learn more about programming.
8	I can use this learning media independently without much help.
9	This learning media effectively teaches computational thinking concepts.
10	I feel more confident in using Scratch after using this media.
11	The time given to complete tasks in this learning media is sufficient.
12	This learning media helps me in completing programming tasks.
13	The material presented in this learning media is in accordance with my learning needs.
14	I can understand and apply the concept of buoyancy in programming using Scratch.
15	This learning media improves my computational thinking skills.

Similar to the validity instrument, the practicality instrument also provides a space for practitioners to provide suggestions and input regarding the development of the media that has been carried out, which is useful for improving the media to be better.

Data analysis was conducted by finding the average score of validity and practicality. The Scratch learning media validity and practicality indices are stated as valid and practical if the average score of all items is as stated in Table 3.

Table 3. Validity and practicality criteria

Average Score Interval (%)	Categori
$81,25 < x \leq 100$	Very Valid/Very Practical
$62,5 < x \leq 81,25$	Valid/ Practical
$43,75 < x \leq 62,5$	Invalid/Impractical
$25 < x \leq 43,75$	Very Invalid/Very Impractical

The categorization of validity and practicality can be obtained the formula:

$$AverageScore = \frac{ObtainedScore}{TotalScore} x100$$

Dissemination

The dissemination was conducted by implementing the Scratch media in learning activities about the concept of buoyancy in elementary schools. In this case, practitioners were also asked to provide feedback on the media used as a final improvement material for developers in perfecting the product's operation. Additionally, dissemination can be done through online platforms to be accessed by more students and teachers from all elementary schools in Indonesia.

RESULT AND DISCUSSION

The research on developing a programming learning medium using Scratch for the concept of buoyancy to enhance computational thinking in elementary schools was conducted effectively, in line with the planned objectives. This study adopts the 4D development model, which was carried out as follows:

Define Stage

Initial Analysis

The abstract nature of the buoyancy concept and computational principles makes them difficult to understand without adequate visualization, and this leads to students struggling to visualize how objects float and sink. Based on the analysis, it's also found that traditional teaching methods is less effective, resulting in students feeling bored and unmotivated in the learning process. In this context, students need explanations linked to real-world scenarios and visualizations that can help them grasp the concept of buoyancy, such as animations or simulations showing how objects float or sink under various conditions. Therefore, the use of Scratch media was chosen to address these issues by providing a more engaging and enjoyable learning experience for students.

Student Analysis

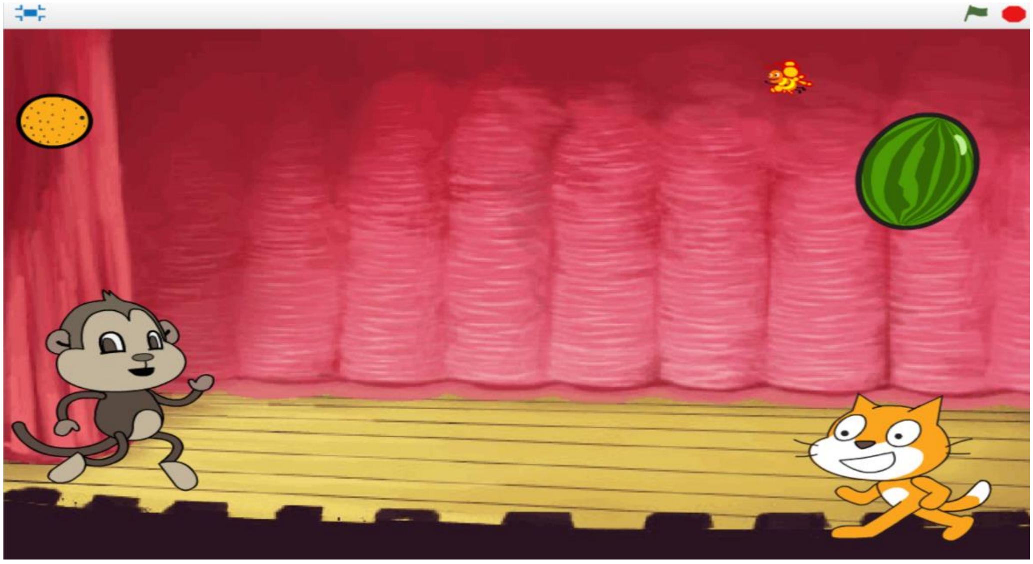
Primary school students, who are in the operational stage, are capable of logical thinking but are limited to applying logic to physical objects. As a result, the creation of Scratch media is ideally suited to aiding students in comprehending abstract ideas. Furthermore, media utilization is a very effective way to accommodate different learning styles, such as kinesthetic, visual, or auditory.

Design Stage

The first step taken by the researchers in designing the educational media product was to organize the learning material that would be presented, including theories, examples, and exercises related to the buoyancy concept. Additionally, designing the storyboard and flow of the media was crucial to ensure that the content is structured and logical. The main development team and development schedule were also determined during this stage, with the timeline set from January to August 2024. Expert validators and practical evaluators were selected according to their relevant fields to ensure that the media assessment could be carried out appropriately.

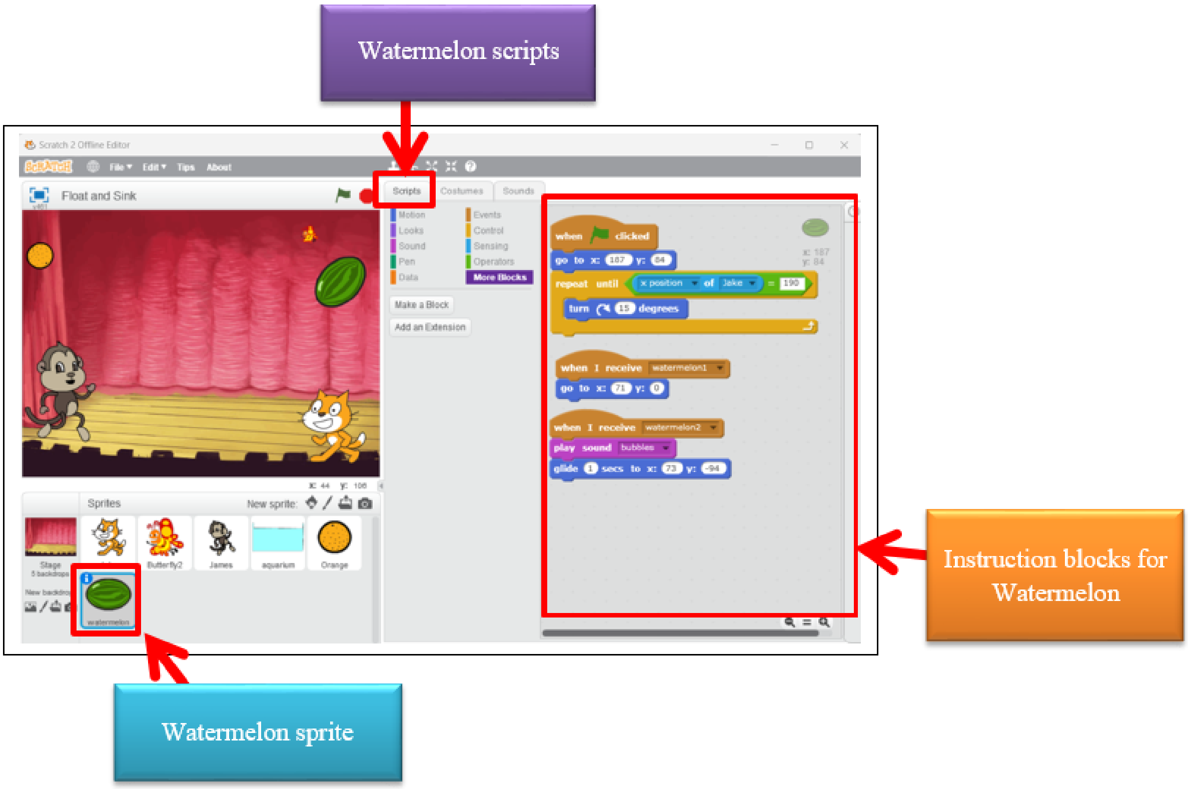
Development Stage

The project of Science concept: Buoyancy was developed. In the project, students are asked to place both fruits in water and then observe each object and explain why it behaves that way. To place the two fruits, students need to give instructions to the sprites named James and Jake. Please help James and Jake by following Steps A through D.



Click the designated button  and follow the instructions, then select the Orange sprite and input the command blocks as shown in the red box within its script space.

Step C: Click on the **Watermelon sprite**. In the **Watermelon script** space, input command blocks as shown in the red box in the **Watermelon script** space.



Some snippets of the simulations can be seen in Figure 10 as follows.

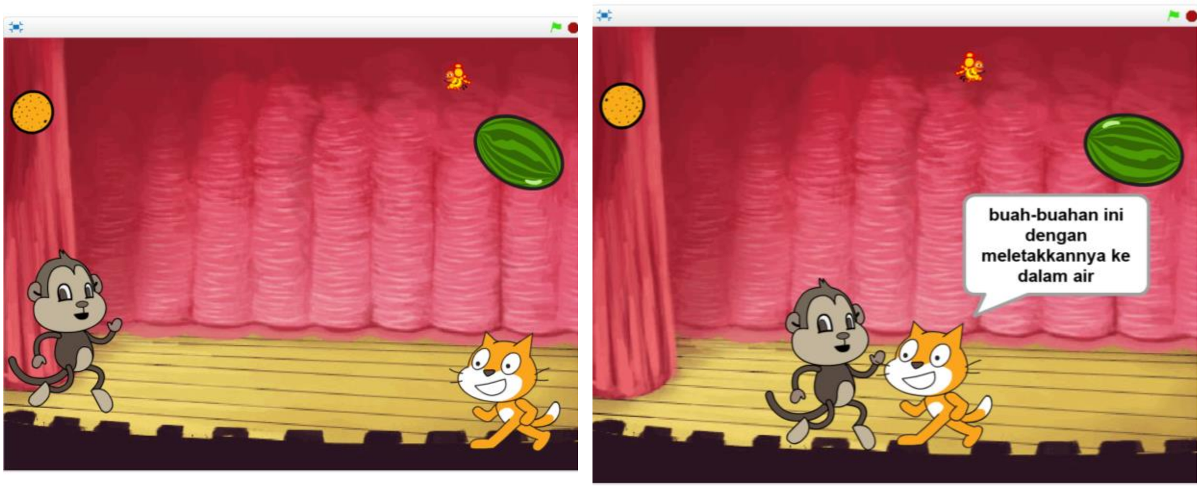


Figure 10. Snippets of Buoyancy concept simulation

Validity Results

The validation process is an important step in ensuring the accuracy, relevance, and quality of a developed learning media. The results of this expert validation provide a clear picture of the extent to which the developed media meets the expected criteria, and provide recommendations for improvements needed to improve its validity and reliability. This study involved 3 experts who each assessed the validity of the media to be implemented in the learning process in Elementary Schools. The results of expert validation can be seen in Table 4.

Table 4. Expert Validation Results

Indicator	Percentage of Each Indicator (%)	Category
Display Design	70,25	Valid
Navigation	79,15	Valid
Conformity Content	80,25	Valid
Interactivity	82,14	Very Valid
Technical suitability	80,55	Valid
Mean	**78,47**	**Valid**

The results of expert validation of the developed learning media indicate that the media generally meets the expected validity criteria. Validation was carried out by three experts who evaluated the media based on several important indicators, namely display design, navigation, content suitability, interactivity, and technical suitability. Based on the validation results, the "Interactivity" indicator received the highest rating with a percentage of 82.14% and was categorized as "Very Valid." This shows that the programming learning media using Scratch on the Buoyancy Concept is very good at involving interaction between users and media, which is an important aspect in learning effectiveness.

Other indicators such as "Content Suitability" and "Technical Suitability" also obtained quite high scores, 80.25% and 80.55% respectively, and both were categorized as "Valid." This indicates that the content presented is in accordance with the learning objectives and that the technical aspects of the media already support its use in the learning environment. The "Navigation" indicator obtained a score of 79.15% and was also categorized as "Valid," meaning that users can easily navigate this learning media. Meanwhile, the "Display Design" indicator obtained the lowest score, which was 70.25%, but was still included in the "Valid" category, indicating that the media display was quite good with minor improvements such as the colors and fonts used.

Overall, this learning media has an average validation percentage of 78.47%, which categorizes it as "Valid." Thus, this programming learning media using Scratch on the Buoyancy Concept is feasible to be implemented in the learning process in Elementary Schools, although there are several aspects that can be further improved based on recommendations from experts.

Practicality Results

After conducting the validity and revising the learning media according to expert recommendations, the next step taken was to assess the practicality of the learning media by involving 10 elementary school students. This practicality test aims to evaluate the extent to which this learning media can be applied effectively in a classroom environment, as well as to identify the ease of use and students' understanding of the material presented. The results of this practicality test will provide an overview of how students respond to the use of Scratch in learning the concept of buoyancy, as well as measure whether this media can significantly improve their understanding of the material. The results given by students during the practicality test can be seen in Table 5.

Table 5. Practical Test Results

Question	Percentage of Each Indicator (%)	Category
The Scratch-based learning media is easy to understand.	72,54	Practical
The instructions in the learning media are clear and easy to follow.	70,45	Practical
I feel happy when using this learning media.	82,25	Very Practical
This learning media helps me understand the concept of buoyancy well.	74,33	Practical
I can follow the programming steps in Scratch without difficulty.	72,52	Practical
This learning media is interesting and makes me more interested in learning programming.	74,80	Practical
This learning media motivates me to learn more about programming.	72,34	Practical
I can use this learning media independently without much help.	78,35	Practical
This learning media effectively teaches computational thinking concepts.	74,80	Practical
I feel more confident in using Scratch after using this media.	80,15	Practical
The time given to complete tasks in this learning media is sufficient.	73,45	Practical

Question	Percentage of Each Indicator (%)	Category
This learning media helps me in completing programming tasks.	75,52	Practical
The material presented in this learning media is in accordance with my learning needs.	79,60	Practical
I can understand and apply the concept of buoyancy in programming using Scratch.	73,15	Practical
This learning media improves my computational thinking skills.	78,50	Practical
Mean	**75,52**	**Very Practical**

The results of the practicality test of Scratch-based learning media to teach the concept of buoyancy to 10 elementary school students showed that overall this media was considered very practical. Each indicator tested in this study, such as ease of understanding, clarity of instructions, student satisfaction, and effectiveness in teaching concepts, scored high, with an average reaching 75.52%, which is categorized as "Very Practical". The indicator "This Scratch-based learning media is easy to understand" scored 72.54%, which is categorized as "Practical", indicating that students can understand the material well through this media. The indicator "The instructions in this media are clear and easy to follow" also showed similar results with a score of 70.45%. This indicates that the guidance provided in the learning media is clear enough so that students can follow the programming steps without difficulty.

A very positive thing is seen in the indicator "I feel happy using this learning media", which scored 82.25% and was categorized as "Very Practical". This indicates that this media is not only effective in delivering material, but also fun for students, increasing their interest in learning programming. In addition, the indicators "This media makes me more interested in learning programming" and "This media increases my confidence in using Scratch" also received high ratings, 74.80% and 80.15% respectively, which are categorized as "Practical". Students also felt that this media helped them in completing programming tasks and taught the concept of computational thinking well, with both indicators scoring 75.52% and 78.50% respectively, indicating that this media not only supports programming learning but also improves students' problem-solving skills.

According to this study, Scratch was a successful teaching tool for the abstract idea of buoyancy, resolving a typical issue with conventional approaches where students frequently find it difficult to understand the concepts of floating and sinking. Students were able to manipulate items and see firsthand how changes in variables like size or density affected buoyancy thanks to Scratch's interactive, visual simulations. This aligns with findings from other studies (Ideris et al., 2019; Lubis et al., 2023; Herawati et al., 2024), which highlight the power of interactive media in helping students understand complex scientific phenomena by visualizing them in action. As maintained by Lopez and Hernandez (2015), in contrast to theoretical explanations alone, Scratch allowed students to experiment with real-time variables, which improved their knowledge of abstract scientific principles and helped them develop a clearer understanding of cause-and-effect linkages in physics.

In addition, using Scratch is known to make students more interested and engaged when learning (Lubis et al., 2023). Particularly for younger students, Olitsky and Milne (2012) stated that the dry or abstract nature of traditional science instruction can cause disengagement. However, because Scratch-based learning is interactive, students participated more actively and showed excitement as they experimented with their own ideas and studied simulations (Nurhalizah & Jayanti, 2023; Belessova et al., 2024). The learning process was both enjoyable and instructive thanks to this interactive, captivating strategy that seems to hold students' interest better than traditional techniques (Dohn, 2020).

Furthermore, Pérez-Marín et al. (2020) added that there is a significant degree of student learning participation increase with Scratch. This indicates that interactive, gamified learning environments might inspire students to become more involved in their education (Sáez-López et al., 2016; Chou, 2020). As claimed by Kong and Wang (2019), students are more likely to feel engaged in the learning process when they are given the freedom to provide content, such as by creating their own simulations. This is in line with research from other studies that shows how game-like instructional tools can improve motivation and strengthen students' bonds with the subject matter (Zarzycka-Piskorz, 2016; Alabbası, 2017; Cheung & Ng, 2021).

Overall, these results indicate that this Scratch-based learning media is very practical and effective in teaching the concept of buoyancy, and is liked by students, making it a powerful tool in the classroom learning process.

CONCLUSION

The conclusion of this study shows that the use of Scratch as a teaching tool for the concept of buoyancy has proven effective in improving students' understanding. Students who participated in learning using Scratch experienced a significant increase in their understanding of basic physics concepts, especially related to buoyancy. In addition, the use of Scratch also succeeded in increasing student engagement and interest in learning, which are important factors in the learning process. The implementation of Scratch as a learning medium provides an interactive experience that helps students visualize abstract concepts and apply them in real situations, so this method is worth considering as part of the elementary education curriculum.

The implications of this study suggest that using Scratch in primary science instruction might greatly improve student comprehension of difficult ideas like buoyancy while also encouraging critical computational thinking abilities. Scratch helps close the gap between theory and real-world use by offering an interactive, captivating method for visualizing and experimenting with complex concepts, which makes learning more approachable and inspiring for students. Based on these findings, it is recommended that schools include Scratch-based learning resources into their curricula, provide teacher training to guarantee successful implementation, and broaden the use of this technology to teach further scientific topics in light of these findings. Furthermore, encouraging student creativity through project-based learning and looking more closely at Scratch's long-term effects on academic achievement would assist maximize its potential in influencing future teaching methods.

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