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A Stone Can Bounce on the Surface of Water: A Conceptual Physics Analysis Study of Students

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Abstract: Throwing a stone on the surface of the water has been a popular hobby for thousands of years, but in recent times, this phenomenon is rarely encountered in physics education. Flat and round stones are the best choice due to their favorable surface area, which creates a rebound when they collide with the water. However, the "magic angle" between the rotating stone and the water must be around 20 degrees to achieve the maximum number of bounces. This is an interesting phenomenon to explore, especially for students in rural areas who often visit rivers or beaches to play. Therefore, this study was conducted to analyze the conceptual understanding of physics students regarding the phenomenon of stones bouncing on the surface of water. This research is a qualitative study that analyzes students' responses through direct questions posed by the teacher. The study was conducted with 20 ninth-grade students at SMP Negeri 81 Maluku Tengah. The findings show that students have a very weak understanding of the physics concepts related to the stone-bouncing phenomenon. They are unable to explain the phenomenon scientifically because they are still influenced by answers based on local and cultural experiences. As a result, the teacher took action by engaging students in direct learning and providing clear explanations of the concepts. Consequently, students' conceptual understanding of physics improved, and they were able to explain the phenomenon scientifically.

Keywords: Conceptual understanding; Physics education; Stone bouncing on water

Introduction

Many science educators suggest that physics education should start as early as possible in junior high school. However, around the world, most middle school science teachers lack both the knowledge and enthusiasm to teach physics. For instance, in Israel, most middle school science teachers (80%) have a background in biology (Zuzovsky, 2003), their knowledge of physics is limited, and they are unsure of their ability to teach the subject (Mualem & Eylon, 2009). Additionally, many students find physics difficult due to the complex concepts and mathematical calculations involved in learning it (Ayasrah et al., 2024). Many students struggle to understand the material and may require additional support to succeed in class (Alabidi et al., 2023). According to Roth & Roychoudhury (1993), the primary goal of physics education is to equip students with the knowledge necessary to apply physics concepts and principles to solve problems and to develop an understanding of the universe.

Several research findings indicate that students face difficulty in understanding the basics of physics, including concepts such as force, acceleration, displacement, and gravitational acceleration (Rahman & Watanobe, 2023). One reason mentioned is that most students struggle to understand Newton's second law of motion, as evidenced in the United Arab Emirates (UAE) (Alarbi et al., 2024). Another study shows that only 35% of students consider physics concepts when solving physics problems, with most students almost never drawing physics diagrams (Snetinova & Koupilova, 2012). Furthermore, students often struggle to connect different physics concepts. There is also evidence suggesting that girls may find physics more challenging than boys, potentially due to factors such as classroom environment and teaching quality. Despite its crucial role in technological progress and economic development, physics remains a challenging subject for many students, particularly girls (Zulkiffli et al., 2024).

Physics education today is shifting from merely an exchange of knowledge, given and received through lectures where students mimic experimental operations,

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to creating an environment where students actively participate in the process of scientific inquiry and independently acquire knowledge (İnce et al., 2015; Cai et al., 2021). Successfully learning to solve problems in the scientific domain, such as physics, requires the construction of conceptual knowledge (Peter & Uwamahoro, 2023). However, a survey of over 5,000 physics students across 30 institutions showed that the conceptual understanding of students enrolled in physics courses is unsatisfactory (Maloney et al., 2001). Instead of striving to build conceptual understanding of physics to solve word problems, students use formula-centered translation strategies when solving problems (Jonassen, 2003). In addition to the use of formula-based solution strategies, students' difficulties in building scientific conceptual understanding in physics are also caused by misconceptions developed based on perceptions gained from everyday life (Hung & Jonassen, 2006). Physics education for the 21st century aims to foster higher-order cognitive skills such as critical thinking, metacognition, and deep conceptual understanding (Bao & Koenig, 2019). Conceptual understanding is permanent and difficult to correct once it is embedded in mental structures (Badruldin & Alias, 2022). Several factors are believed to affect students' attitudes toward conceptual understanding in introductory physics courses: ineffective teaching methods, misconceptions carried over from pre-college education about physics, negative attitudes toward learning physics, weaknesses in critical thinking, inadequate math skills, poor problem-solving techniques, poor testing methods, and uncomfortable evaluation methods may all be contributing factors (Malkawi et al., 2013). A study in Nigeria showed that 50% of the concepts in the physics curriculum are considered difficult by students, while 44% of the concepts are considered difficult by teachers. These difficult concepts include Waves, Light Waves, Sound Waves, Pressure, Electricity, Magnetism, and Nuclear Physics (Obafemi & Onwioduokit, 2013).

Students come to school with their own preconceived notions about how the physical world works. For example, in the Physics concept of falling objects, students already believe that heavier objects fall faster than lighter objects. They also believe that an object needs a constant force to keep moving. These ideas or beliefs are based on their observations of how physical processes work in their surrounding environment. If not properly addressed by the teacher, this can hinder students from learning the actual concept or construction that needs to be learned (Lorenzana & Roleda, 2017). Therefore, identifying prior knowledge and misconceptions is an important step in the teaching process that enables teachers to design an effective learning environment that helps reshape students' initial knowledge into scientifically accepted understanding (Eshach, 2014). Assessing or measuring the level of student understanding will also help teachers develop teaching strategies that are more suited to students' abilities and interests.

Children begin the process of acquiring knowledge by organizing their sensory experiences, influenced by culture and everyday language, into narrow but coherent explanatory frameworks that may not be based on the latest scientific theory (Vosniadou & Ioannides, 1998). According to various studies, this knowledge is referred to as nonscientific knowledge, conceptions, or misconceptions (Dumais & Hasni, 2009). Research in science education provides clues and indications to help students acquire scientific concepts and transform existing conceptions, a process known as conceptual change. The concept of conceptual change varies among theorists; however, most researchers share the same goal—student learning. In science education, conceptual change models influence science learning, science teaching, learning to teach science, and teaching how to teach science (Vosniadou, 2002). Teaching strategies that encourage conceptual change are grouped into three categories: developing cognitive conflict, applying analogies, and facilitating cooperative and collaborative learning to encourage collective discussion of ideas (Limón, 2001).

Conceptual change refers to the gradual revision of children's beliefs from intuitive (and often incorrect) concepts to more complete and correct concepts; these concepts, whether intuitive or complete, are called explanatory frameworks. An explanatory framework can be measured by the strategies used when solving problems, as the strategies reflect children's explanatory frameworks (van der Graaf, 2020). Previous research has revealed that, in particular, young children (i.e., elementary school children) are prone to conceptual change and that inquiry-based learning can promote conceptual change (Huang et al., 2017). Physics is crucial in university science education. However, teaching and learning physics remain challenging tasks. One approach to addressing these challenges is the use of multiple representations (MR), which refers to the combination of different modes of representation and aims to communicate abstract concepts in a more concrete way, making them more accessible. Additionally, physics education often involves multiple forms of representation (e.g., text, images, equations, and tables), which require learners to select and integrate information and then build their arguments. Understanding multiple representations is a complex task (Wu & Liu, 2021). Developing new representations to solve problems is a creative effort. If every new problem required its own unique representation, teaching students to represent problems in different ways, while a worthy goal, would be impractical.

The use of MR in learning environments is now common, as teachers often use representations to make complex and abstract concepts accessible through various forms of visualization. Research shows that the use of MR can enhance student learning (Klein et al., 2018). However, studies also show that students struggle with connecting and integrating representations and translating information between them (Bollen et al., 2017). The results of this review study provide evidence that MR can function as an empowering learning tool in teaching physics at the university level. Furthermore, MR can be used as a tool to understand how students construct and use MR during problem-solving and how this process can support individual student needs (Munfaridah et al., 2021). One of the most common ways to communicate scientific ideas is through visual representations, which also play an important role in physics teaching (Chen & Gladding, 2014). In addition, Hill et al. (2015) recommend the use of representations such as words, graphs, equations, and diagrams to support student learning. When discussing the role of MR in physics teaching and learning, Opfermann et al. (2017) demonstrate that MR has great potential in supporting students' understanding of physics concepts, as students learn more easily when problems include MR. Therefore, the use of MR can maximize the outcomes of the students' learning process. Thus, the aim of this study is to analyze the conceptual understanding of students related to the phenomenon of a stone skipping on the surface of the water.

Method

This study is a qualitative case study that analyzes student responses through direct questions posed by the teacher. A case study approach is used where each student is considered a case, and their conceptual reasoning regarding a physics problem is analyzed using the theoretical framework of ontological categories. The analysis essentially involves searching for data available to the researcher to attribute students' substance-based conceptions to the concept of force. Cooperative inquiry is used as a teaching tool to help students understand and analyze ontological categories as a theoretical framework. In this investigation, the role of the researcher is distributed among the entire class by involving them in reading related literature, analyzing case examples, and conducting a retrospective analysis of their own conceptual difficulties related to the concept of force. The data that emerges from this investigation is used to analyze the students' own interpretations of their conceptualizations of the concept of force. In the following section, the participants, classroom setting, and data sources are outlined (Özdemir, 2015). The study was conducted with 20 ninth-grade students at SMP Negeri 81 Maluku Tengah. The main goal of this course is to help students understand the nature of alternative conceptions and acquire basic knowledge and skills in physics, such as cognitive conflicts, anchoring/bridge analogies, extreme case reasoning, ontological category shifts, and the learning cycle. Data were collected during the academic year 2024/2025. All students involved in this study had already learned basic physics concepts in the first and second years, so this knowledge helped them learn about the concept of throwing a stone on the surface of water.

Result and Discussion

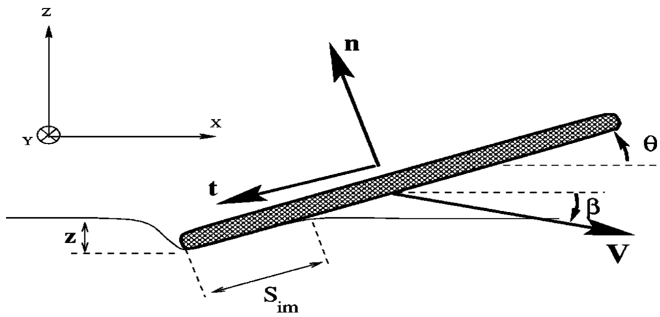
In the last two decades, many researchers have sought innovative new approaches in physics teaching. Some have systematically gathered and organized previous research based on specific domains. The primary role of conceptual physics learning is the empirical experience of naturalistic laws, rather than its mathematical background. In this study, we have investigated the effectiveness of this learning approach in Slovenian secondary schools. The findings of this research suggest that conceptual learning enables students to better understand physics concepts, which, in turn, improves student learning outcomes. The new generation of students and the rapid advancement of modern technology encourage educational researchers to continually search for new, appropriate teaching approaches (Ülen & Gerlič, 2012).

In a survey about why secondary school students in the UK are not interested in studying physics, the main reason given by students was that they perceive physics as a difficult/harsh subject (Williams et al., 2003), and they have lower expectations of their ability to complete physics tasks (Barmby & Defty, 2006). Conceptual understanding of Newtonian Physics in its most basic form involves understanding the principles of science, especially Newton's Laws, which are used to explain and predict observations of the natural world, and knowing how to apply this understanding efficiently in the design and execution of scientific investigations and in practical reasoning. Conceptual understanding requires knowledge and the ability to use scientific concepts to develop mental models of how the world works according to the latest scientific theories (Saleh, 2011). Typically, specific representations are used in physics teaching in one of three modes: a) as a means to explain a problem, such as when a student draws a sketch of a physical situation and summarizes the given information; b) as the subject of a problem, such as when a student is explicitly asked to draw a graph or find the value of a physical quantity using a graph; and c) as a step in a formal procedure, such as when students are required to draw a free-body diagram as one of the first steps in applying Newton's laws to solve a problem (Dufresne et al., 1997). Several questions posed by students during the training, which can be recorded in the following transcript, were as follows:

S2 : *Why is it that when we throw a small stone with a flat and somewhat round surface on the surface of a river or lake, the stone will bounce on the water?*

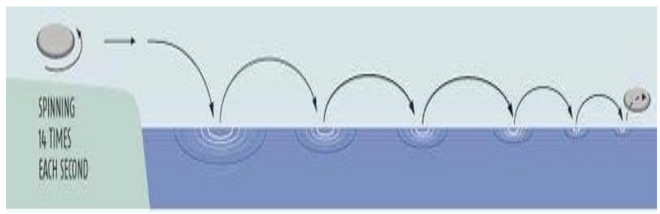
T : 1. *the stone touches the water, the impact force pushes some of the water downward, which in turn forces the stone upward. If the stone is moving fast enough to reach the threshold of the minimum speed, it will bounce. If not, it will sink. A round, flat stone is the best because its surface area displaces more water when it bounces.*
2. *A stone will only bounce if its initial speed exceeds a certain value. If the stone is also spinning, this introduces stabilizing torque that can maintain the angle at which it hits the water—this helps the stone to bounce again.*
3. *The stone bounces across the water due to the combination of the angle at which it is thrown and the speed at which it is thrown. The stone needs to have a certain amount of speed to bounce off the surface of the water, and the angle at which it is thrown affects how much speed is lost when it touches the water.*

Stone skipping is typically a good area for applying mathematics and physical science; however, Lazzaro Spallanzani (1729-1799), an Italian Catholic priest, is known as the first person to provide a scientific explanation of how stones bounce on water. After him, there seems to have been a long gap in research until a French physics professor, Lyderic Bocquet, brought this topic into the scientific field with an article published in 2002, followed by another article in 2004. Professor Bocquet revealed that the angle of throw and the stone's initial linear speed are also important factors. He was the first to coin the term "Magic Angle." According to the professors, everything depends on the principle of momentum conservation, which states that when the stone enters the water and pushes some of it downward, the stone, in turn, is forced upward. However, the stone must be moving at a certain speed—at least one kilometer per hour—otherwise, the stone "skims" the water for a short distance and then sinks (Bocquet, 2003).



Source : (Bocquet, 2003)

Figure 4. Schematic view of the collisional process of a flat stone encountering a water surface. The stone has a velocity V, with an incidence angle b, while u is the tilt angle of the stone. The immersed area Sim represents the area of the stone in contact with the water surface. The depth of the immersed edge is z.



Source: https://www.newscientist.com/

Figure 5. Jerdone Coleman-McGhee bounced a stone 38 times on the Blanco River, Texas in 1992

In principle, throwing a stone faster will help it achieve the maximum number of bounces, although in practice, the impact speed does not need to be very high (Truscott et al., 2014). Physics education plays an important role in shaping students' understanding of the natural world and their critical thinking skills (Ng & Nguyen, 2006). However, across middle schools, it is increasingly recognized that students face various challenges when learning physics concepts. Understanding and addressing the learning difficulties faced by students in the field of physics is an important effort with multifaceted significance in shaping the educational landscape and the broader societal order. Understanding the nature of these difficulties is crucial for improving the quality of science education at this critical stage of education. Middle school students, typically aged between 11 and 15 years, are at a developmental stage where their cognitive abilities are rapidly developing (Wigfield et al., 1996). Physics, which is often introduced as a distinct subject at this level, presents conceptual challenges that may not align with their previous learning experiences. The transition from more concrete scientific concepts taught in earlier grades to more abstract and complex ideas in physics can create significant barriers for many students (Shrestha et al., 2023).

How is it that when you throw a stone into the sea, it doesn't immediately sink but bounces several times? "The phenomenon where a stone can bounce several times on the water's surface when thrown at a certain angle in physics is known as stone skipping. To understand this phenomenon, we need to consider several principles of physics, including: Throwing Angle: To produce stone skipping, the stone is thrown at a small angle to the surface (usually around 10–20 degrees). At this angle, the stone "cuts" across the water surface at a fairly flat angle, so the water acts as an elastic barrier that can bounce the stone back into the air. Speed and Kinetic Energy: When the stone is thrown, it has kinetic energy that is divided into horizontal components (pushing the stone forward) and vertical components (pushing the stone upward). To bounce, the stone needs a sufficiently high speed, particularly in the horizontal component, to keep moving forward across the water without immediately sinking. Surface Tension and Lift Force (Archimedes' Force): The surface of the water has tension, which helps the stone bounce when it strikes the water at the correct angle. When the stone hits the water, if the angle is shallow and the speed is high, the surface of the water generates an upward lift force that can support the stone and bounce it back into the air. Rotation (Spin): When throwing the stone for skipping, the stone is typically spun (given a spin). This rotation is important because it helps stabilize the stone during the bounces and allows it to maintain the correct throwing angle, reducing the likelihood that the stone will sink after the first bounce. The rotation also produces a gyroscopic effect that helps maintain the direction of the stone, allowing it to stay on the water's surface for a longer time. Energy Loss with Each Bounce: Each time the stone touches the water, some of its kinetic energy is lost due to the drag force of the water. After several bounces, the stone's kinetic energy decreases to the point where it is no longer sufficient to generate the lift force needed to bounce the stone back, and eventually, the stone will sink."

Using basic physics, based on Newton's laws of motion, it is possible to estimate the ideal trajectory of a stone skip using a simple computer program. Students can practice their math and science skills, as well as coding skills, by creating a mathematical model of stone skipping and then testing its predictions experimentally with actual stones and throws through careful video analysis. Students who wish to delve deeper into the fluid-structure interaction between water and the skipping stone can also explore this (Babbs, 2019). Teachers in schools still fail to connect physics themes to real-life examples. Furthermore, students enter the classroom throughout the year with the same types of procedures, settings, assets, questions, and assessment methods, making the learning process tiresome for them. In such conditions, students not only struggle to understand and apply scientific ideas (Akhter et al., 2019). Cognitive barriers, stemming from the abstract nature of physics principles and their mismatch with everyday experiences, pose significant challenges for students in understanding these complex concepts. Studies in cognitive science and educational psychology have highlighted the importance of addressing misconceptions and learning difficulties among students in the context of scientific subjects (Taber, 2014). Previous research has shown that these challenges are not only related to the inherent complexity of physics concepts but also to teaching methodologies, curriculum design, and individual students' learning styles. Furthermore, mastering physics at the middle school level lays the foundation for further learning in the field and related disciplines at higher levels of education. Therefore, identifying and understanding the specific areas of difficulty faced by students in physics is crucial for developing targeted interventions and pedagogical strategies to support their learning.

The aim of this research is to comprehensively analyze and identify the diverse spectrum of learning difficulties faced by middle school students in understanding physics content (Cobb Morocco & Mata Aguilar, 2002). By delving into these challenges, this study seeks to provide insights that can help educators, curriculum developers, and policymakers tailor teaching approaches and educational materials to better support students' understanding and mastery of physics concepts during this formative stage of education. This study aims to contribute to the broader discourse on science education by uncovering specific barriers that hinder effective physics learning at the middle school level, ultimately aiming to improve the overall quality of science education and students' academic achievement. Interestingly, girls show a higher level of interest in physics than boys. A different pattern was observed in Georgia, where girls showed more interest in physics than boys. This is a promising result for engaging girls in physics. Overall, the average interest score in physics is not high, indicating that changes in teaching approaches and curriculum content are needed to better engage students in the learning process in Georgia (Kapanadze et al., 2023).

Conclusion

Based on the results of the study, it can be concluded that the throwing angle plays a key role in stone skipping. To achieve stone skipping, the stone is thrown at a small angle to the surface of the water (usually around 10–20 degrees). This angle allows the stone to "cut" across the water's surface at a fairly flat angle, causing the water to act as an elastic barrier that can bounce the stone back into the air. In terms of speed and kinetic energy, when the stone is thrown, it will have kinetic energy that is divided into horizontal components (pushing the stone forward) and vertical components (pushing the stone upward). To cause the stone to bounce, it needs to have a sufficient speed, particularly in the horizontal direction, so that it can continue moving forward above the water without sinking immediately. Regarding surface tension and the lift or Archimedes force, the water's surface has tension that can help the stone bounce when it touches the water at the right angle. Another finding of the study shows that students have a very weak understanding of the physics concepts related to the stone skipping phenomenon on the water's surface. Students are unable to explain the phenomenon scientifically because they are still stuck with answers based on local and cultural experiences. Therefore, the teacher took action by teaching students through direct instruction and explaining the concepts in a way that was appropriate for them. As a result, the students' conceptual understanding of physics improved, and they were able to explain the phenomenon scientifically.

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The authors declare no conflict of interest.

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