Journal of Pedagogical Research
Volume 7, Issue 5, 2023
https://doi.org/10.33902/JPR.202322724

Research Article

The effects of the multiple representation approach on undergraduate students' understanding of the Archimedes' principle

Jeanne Kriek[1] **and Ashenafi Legesse**[2]

[1]*University of South Africa, South Africa (ORCID: 0000-0001-6248-4563)*
[2]*University of South Africa, South Africa (ORCID: 0000-0002-3161-2822)*

Students often face difficulties to understand Archimedes' principle and to apply it in everyday life. It is therefore necessary to explore a different teaching approach that addresses students' visual and auditory senses in a unique manner. The aim of this study was to determine the effect of using multiple representations on undergraduate physics students' understanding of Archimedes' principle. A quasi-experimental approach was employed, involving the random selection of four groups of students (experimental and control) with two iterations, each involving two groups of students. A sample of 128 students completed an open-ended questionnaire based on the Thermal Transport Conceptual Inventory, and the Fluid Mechanics Concept Inventory. Lesson plans were presented for both iterations. Quantitative analysis involved the use of t-tests to assess the comparability of the groups, prior to the intervention and ANCOVA after the intervention to determine the effect. Qualitative data analysis involved identifying and comparing themes to establish student understanding before and after the two iterations. The findings indicated that the use of six different representations did not yield a significant effect compared to traditional teaching, while the use of eight representations proved significantly effective where the static pictures were replaced by animation pictures as well as adding videos and virtual labs. Careful planning is crucial not only for selecting the most suitable representation in a particular teaching situation, but also for determining which technology to use when addressing students' understanding of Archimedes' principle.

Keywords: Archimedes' principle; Buoyant force; Multiple representations; Undergraduate physics students

Article History: Submitted 23 June 2023; Revised 27 September 2023; Published online 20 November 2023

1. Introduction

Students often do not fully grasp the concept of the Archimedes' principle (Diyana et al., 2020). The Archimedes' principle states that an object immersed in a fluid experiences a buoyant force that is equal in magnitude to the force of gravity on the displaced fluid. Students often think that the buoyancy force is the resultant force exerted by fluid pressure on an object, while others still mistakenly believe that the immersed object's Archimedes force is influenced by the depth of the object (Diyana et al., 2020; Loverude et al., 2003). An everyday life example is when a ship is launched in the ocean, it sinks until the weight of the water it displaces is equal to its own weight.

Address of Corresponding Author

Jeanne Kriek, PhD, University of South Africa, 360 Anderson Street, Menlo Park, South Africa.

kriekj@unisa.ac.za

How to cite: Kriek, J. & Legesse, A. (2023). The effects of the multiple representation approach on undergraduate students' understanding of the Archimedes' principle. *Journal of Pedagogical Research, 7*(5), 291-306. https://doi.org/10.33902/JPR.202322724

The ship sinks deeper if it's loaded, displacing more water, until the magnitude of the buoyant force matches the weight of the ship and its load.

Studies show that it is important for undergraduates to be taught in a variety of ways (Kohl & Finkelstein, 2006; Volkwyn et al., 2020), as it can improve their comprehension skills (Bakó-Biró et al., 2012). Since students prefer a variety of representations, researchers in the field of fluid mechanics agree that teaching using a method of multiple representations (MRs) could make a difference (Hartini et al., 2020; Minichiello et al., 2020). Studies show that physics students are more successful in problem-solving when using MRs principles (Gestson et al., 2018), as their ways of understanding may differ because of the different ways they might approach a problem (de Cock, 2012; Fredlund et al., 2015). Hence, it is a good idea to use all kinds of representations to engage students, and this allows students to be more successful in understanding basic physics using MRs (Abdurrahman et al., 2019).

Multiple representations are the expression of a concept in many ways, such as using text (verbal descriptions), sketches, diagrams, graphs, and mathematical equations (Airey et al., 2019; Eichenlaub & Redish, 2019; Euler & Gregorcic, 2018; Franke et al., 2019; Geyer & Kuske-Janßen, 2019). Using MRs can even help students improve their creative thinking during problem-solving (Bicer, 2021). MRs enable teachers to improve students' learning outcomes in the classroom, which are consolidated through providing them with different ideas and technical equipment to enhance their learning of physics (Hartini & Sinensis, 2019). Most of the research in physics on MRs has been done on kinematics, mechanics, and physics courses (Volkwyn et al., 2020) not on Archimedes' principle while previous studies have used either three or four representations (Hartini & Sinensis, 2019).

On the one hand, using MRs to engage students allows students to be more successful in understanding basic physics using MRs (Abdurrahman et al., 2019), on the other hand, using MRs is difficult and expensive. Having a variety of representations to explain one concept is time-consuming and requires technological advancements to implement in a class (Martinez & Rebello, 2012); it also may not be effective for all subjects. It requires money, time, energy, and technology (Bakó-Biró et al., 2012). Another obstacle to using this method is that students are not familiar with this approach of explaining one concept in different ways and they could experience ambiguities while using MRs simultaneously (Kohl & Finkelstein, 2006). This needs to be additionally addressed. According to these authors, the MRs approach is a poor teaching method for satisfying the interests of all students. It also places an additional burden on physics teachers when they need to modify their approaches depending on students' social, cultural, academic, and language backgrounds to improve their learning abilities. The MRs approach needs to use multiple learning domains like cognitive and psychomotor so that physics learning can become more meaningful.

There is therefore a need to establish the effect of MRs on the understanding of Archimedes' principle compared to traditional teaching which is the aim of the study. Despite the challenges associated with using MRs, it would seem that the benefits of using MRs outweigh the drawbacks.

2. Theoretical Framework

The Variation Theory of Learning [VTL] offers a theoretical framework from which to explore possible variations in experience and the resulting differences in learning and understanding. According to the variation theory, there are a limited number of features of a given phenomenon to pay attention to at any given time. Two individuals who experience the same phenomenon may focus on different features and, thus, come to understand the phenomenon differently (Bussey et al., 2013). Therefore, the best way to learn is to understand the similarities and differences between concepts. When students cannot recognise the similarities and differences between concepts, the learning process will be challenging (Michael & Modell, 2003).

The VTL was used as a lens to analyse the learning process and its outcomes based on the categories of description. This analysis was done based on the critical aspects discerned by the students. The categories of description formed the basis for identifying the conceptual difficulties that the groups of students encountered before and after instruction.

3. Method

3.1. Research Design

An experimental design was used to establish the effectiveness of the MRs approach. A random sample of participants was selected into two groups (experimental (N = 32) and control (N = 32)). Both groups resided in two different universities in Ethiopia, referred to as University A and University B respectively.

3.2. Data Collection

Before the intervention, two research instruments were administered to the two groups at the same time and the same instruments were used after the intervention. The two research instruments were the open-ended questionnaire [OEQ] and the Fluid Mechanics Conceptual Inventory [FMCI]. The research instruments were validated at a different university in Ethiopia, using expert consultation while the reliability coefficients for the OEQ and FMCI were found to be 0.81 and 0.85 respectively. The OEQ was developed from the validated thermal transport conceptual inventory [TTCI] developed at the Colorado Institute of Mining Technology (Miller et al., 2006) and reviews the students' fluid mechanics and heat flow knowledge and concepts. It comprises of 12 questions and students also have to show their reasoning. The FMCI (Version 3.4) was developed by Martin et al. (2003) at the University of Colorado and comprises of 26 multiple choice questions. Both these research instruments include questions pertaining to Archimedes' principle (buoyancy force), Pascal's principle, fluid flow, and Bernoulli's principle. However, for the purposes of this research, only the questions related to Archimedes' principle were utilised.

During the first intervention, a lesson was presented to the experimental group 1 (n = 32) which included different MRs namely verbal, text, pictures, diagrams, mathematical equations, and simulations. The pictures, diagrams, equations, and simulations were presented on a screen using a laptop. The only difference between the teaching of the experimental and the control group was that the control group were taught using a blackboard while no simulations were provided. The control group 1 had n = 32 students. The duration of the intervention was two hours. After analysis of the instruments, a second iteration followed with a new group (experimental group 2, n = 32) and (control group 2, n = 32) students. In the second iteration, the representations text, animated pictures, diagrams, mathematical equations, simulations, animations videos, and virtual labs formed part of the intervention. The control group 2 (n = 32) was taught using traditional teaching, similar to the first iteration. The same duration for the intervention was followed.

3.3. Procedure

The lesson plans of the first and second intervention are presented as well as the lesson plan of the class during traditional teaching (see Table 1 and 2).

3.3.1. Lesson plans during first and second iteration using multiple representations (MRs)

When planning the lessons, the content and structure of the Archimedes' principle in Ethiopia's undergraduate physics curriculum were analysed and considered, also to identify students' conceptual difficulties. The lesson plan for Archimedes' principle (buoyancy force) in fluids is explained using MR instruction (see Table 1).

In both lessons, aside from verbal communication, the representations were displayed using a screen, projector, and laptop. In the first intervention, six different modes of representation [MRs] were employed: verbal, text, static pictures, diagrams, mathematical equations, and simulations. In the second intervention, eight MRs were utilized: verbal, text, animated pictures, diagrams, mathematical equations, simulations, animation videos, and virtual labs. The distinction between the two interventions lies in the incorporation of more thoughtfully chosen technologies.

Table 1

The lesson plan for Archimedes' principle (buoyancy force) in fluids when being explained using MR instruction for the experimental group

Lesson 1: 1 hour.

Learning goals: Students will be able to do the following:

- State Archimedes' principle.
- State the buoyancy force.
- Explain the interaction between pressure and Archimedes' principle (buoyancy force).
- Clarify physical quantities such as pressure, P, volume, V, and force, F.
- Demonstrate the applications of Archimedes' principle in real-life situations.

Phases	MR representations:	
	Iteration 1(4 MRs)	Iteration 2 (8MRs)
	Prescribed textbook: Serway and Jewett (2004, p. 395-399)	
Introduction	Introduce: • The Archimedes' principle • Buoyancy • The interaction between molecules in pressure and Archimedes' principle	
Presentation		
	Present the lesson: • Define Archimedes' principle. • Describe the interaction between pressure and buoyancy. • Demonstrate Archimedes' principle by showing a picture of a wooden block immersed in a fluid. Show students how the block and the fluid interact and indicate the pressure difference between the block and the fluid (see Figure 1). • Explain this in terms of buoyancy force that equals the upwards force on the object in the picture (see Figure 2). • Evaluate the relationships and the ratio of their density and volume change by using mathematical equations and formulae. • Support the lesson by showing PhET simulation on the Archimedes' principle .	Present the lesson: Show a picture taken from a video of balancing the ring and block of gold before sinking it in a fluid (see Figure 4). • Define Archimedes' principle. • Discuss Archimedes' principle concerning buoyancy by using the picture. • Discuss what would happen when the block is suspended in the fluid concerning buoyancy. • Show the pressure that the fluids exert on the wooden block. • Describe the relationship between pressure and Archimedes' principle (buoyancy force) by using the diagram. • Explain the relationship between the ratio of density and volume change of the water by using the mathematical formula. • Describe Archimedes' principle concerning buoyancy by using the mathematical formula. Show a video showing that the block of gold sinks more than the ring (Figure 5). Show an animation picture of the relationship between a man's weight and the weight of the water he was displacing (Figure 6). • Explain the relationships of density and volume change of the water. • Describe Archimedes' principle concerning buoyancy. • Show an animation video of the fake crown spilling more water than the one made of pure gold (Figure 7). • Explain the relationship between the ratio of density and volume change of the water. • Show a video of the apparent weight loss due to buoyancy in Archimedes' principle (Figure 8). • Describe Archimedes' principle concerning buoyancy. • Explain the pressure that the fluids exert on the wooden block.
Summary	Summarise pressure and the relationship between pressure and Archimedes' principle.	
Evaluation	**Classwork:** A piece of wood is suspended attached to a string and then immersed in a container of water. • What will happen to the wood? • What will happen to the water height? • What will happen on the reading of the spring balance? • The students will now work in their workbooks to complete the activity in their workbooks individually. • Describe the relationship between pressure and Archimedes' principle (buoyancy force) in Figure 1 and Figure 6 in the different interventions. The teacher provides the correct answers so that students can record the various correct answers.	

The use of text. A verbal-text representation was employed to explain Archimedes' principle during the lesson. By presenting the concepts of Archimedes' principle in written form, students were afforded the opportunity to understand the relationship between pressure and buoyancy.

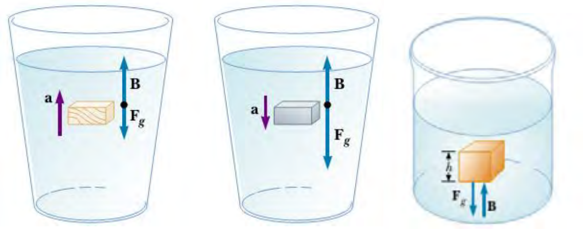
A verbal-linguistic form of representation was utilised to facilitate the exchange of diverse conceptual understandings among students through verbal discussions prompted by activity-based questions. This approach encourages critical thinking.

The use of pictures. Visual aids in the form of pictures were employed to depict the complete submersion of objects in a fluid. The illustrations aimed to convey the concepts related to Archimedes' principle, including buoyancy, pressure interaction, and the equivalence of buoyancy force and the thrust pressure. By observing these visuals, students were able to visualize the transformation and subsequently sketch their own depictions of objects submerged in a fluid.

Figure 1 showcases an illustration that portrays the process of an object being submerged in a fluid and the pressure exerted on the object (Archimedes' principle). This visual aid facilitated students' ability to anticipate and engage in discussions concerning Archimedes' concept of buoyancy.

Figure 1

The submerging of an object in a fluid

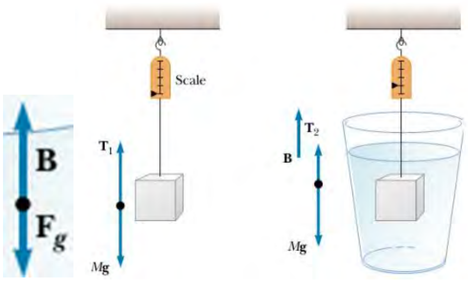


Note. Adopted from Jewett and Serway (2008, p. 397).

The use of diagrams. Diagrams were utilized to exemplify Archimedes' principle, specifically the concept of buoyancy and the interaction between pressure and buoyancy force. In Figure 2, a wooden block is shown, suspended from a thread and subsequently submerged in water. This diagram was projected using PowerPoint during the lecture, while the lecturer provided an explanation of the observed phenomenon. Figure 2 served as a visual stimulus for discussing and exploring the principles at play.

Figure 2

The interaction between buoyancy and pressure - the Archimedes' principle



Note. Adopted from Jewett and Serway (2008, p. 397).

The use of mathematical equations. Symbols and numerical representations were employed to elucidate the ratio between density and volume in Archimedes' principle (see Equation 1 - 4).

To understand the origin of the buoyant force, consider an object immersed in a liquid like in Figure 2 above. The mathematical equations can be used to express the buoyancy. Thus when the object is suspended in air, the tension is equal to its true weight.

When the object is immersed in a fluid, the buoyant force B changes the scale reading to a lower tension value.

$$T_2 = F_g - \mathrm{B} \tag{1}$$

The ratio of the densities is equal to the ratio of the volumes.

$$\frac{\rho_{obj}}{\rho_{fluid}} = \frac{V_{fluid}}{V_{obj}} \tag{2}$$

The density of the object is:

$$\rho_{obj} = \frac{M_{obj}}{V_{obj}} \tag{3}$$

The density of the fluid is:

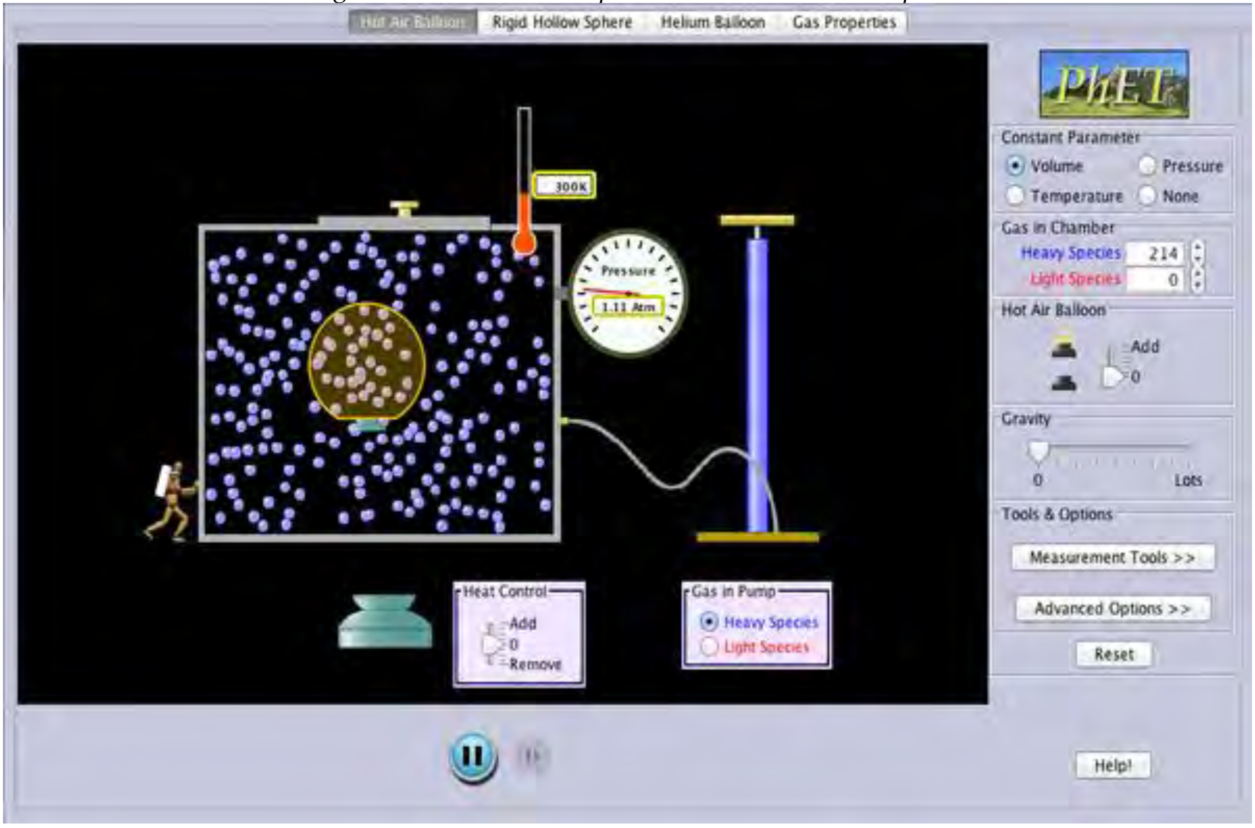
$$\rho_{fliud} = \frac{M_{fluid}}{V_{fluid}} \tag{4}$$

This equation served as a tool for students to gain insight into the interconnectedness of these variables and their impact on Archimedes' principle. By using equations, students were able to grasp the relationships between these variables and visualize them through graphical representations.

The use of interactive simulations. PhET simulations were used to further illustrate the Archimedes' principle. The process was outlined (see Figure 3). Keeping the pressure (P) constant, the top (T) was opened, causing the volume (V) to decrease. Conversely, with the volume (V) held constant, pressure (P) and temperature (T) increased when the pump was operated to add additional molecules. The researcher attempted to simulate this process by maintaining a constant volume (V), adding molecules to achieve a pressure of approximately 1,11 ATM, and adjusting the temperature to 275 K. Subsequently, the researcher modified the temperature from 275 to 300K. However, the pressure showed minimal change, which led the students to conclude that there may have been a leak (30 + 14.7 = 45 (3 ATM)).

Figure 3

PhET simulation illustrating the relation between pressure, volume and temperature



Constant Parameter: ● Volume ○ Pressure ○ Temperature ○ None

Gas in Chamber: Heavy Species 214, Light Species 0

Temperature: 300K

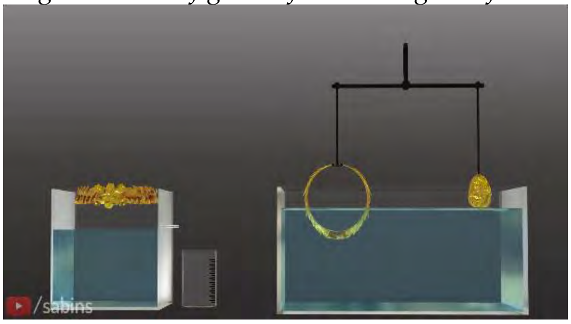
Pressure: 1.11 Atm

Gas in Pump: ● Heavy Species ○ Light Species

Note. Source: https://phet.colorado.edu/en/contributions/view/6775

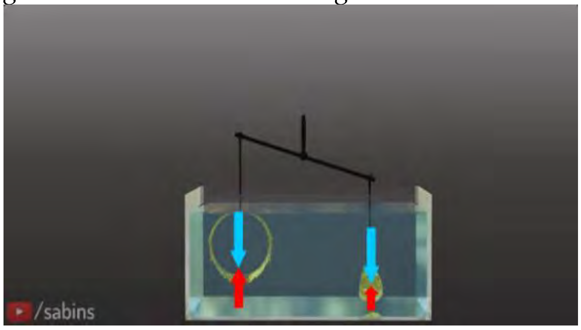
The use of a virtual lab. Students were asked to discuss what would happen if the ring and block of gold were to be immersed in the fluid. They had to describe the relationship between pressure and Archimedes' principle (buoyancy force). The block of gold and ring were then immersed in the fluid, and the pressure that the fluids exerted on the ring and block of gold were explained. The students had to describe the relationship between pressure and Archimedes' principle (buoyancy force).

Figure 4
Picture taken from a video showing balancing the ring and block of gold before sinking in a fluid



Note. Source: https://www.youtube.com/watch?v=XfkJ7wBT-PA&t=181s

Figure 5
Picture taken from a video showing that the block of gold sinks more than the ring



Note. Source: https://www.youtube.com/watch?v=XfkJ7wBT-PA&t=181s

The use of animation video. Archimedes supposedly was asked to determine whether a crown made for the king consisted of pure gold. Legend has it that he solved this problem by weighing the crown first in air and then in water, as shown in Figure 6. The students had to describe Archimedes' principle concerning buoyancy, by explaining the relationship between the ratio of density and the volume change of the water.

Figure 6
Animation picture for the relationship between Archimedes' weight and the weight of the water he was displacing

Note. Source: https://youtu.be/UbUmPApTlg4

Figure 7
Animation picture for the fake crown spilling more water than the one made of pure gold

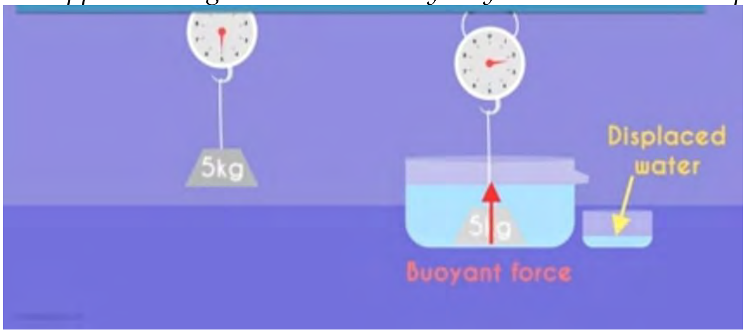
Note. Source: https://youtu.be/UbUmPApTlg4

The use of video. A captured image from the virtual lab provides another representation to conceptualize students' understanding of the buoyant force (see Figure 8). A mass is held completely submerged just below the surface in a container of water. The mass is then moved to a deeper point in the water. Compared to the force needed to hold the mass just below the surface, the figure shows the force needed to hold it at a deeper point. The scale reading is a measure of the forces on the mass.

When the mass is suspended in air, the scale reads the true weight (neglecting the buoyancy of air), when it is immersed in water, the buoyant force reduces the scale reading to an apparent weight. Because the mass is in equilibrium, the net force on it is zero.

Figure 8

The apparent weight loss due to buoyancy in the Archimedes' principle



Note. Source: https://www.youtube.com/watch?v=05WkCPORlj4

3.3.2. Lesson plan during the first and second iteration using traditional instruction

The first and second group of students received traditional instruction. The interaction was between the lecturer, students, textbook and blackboard. The lecturer drew diagrams on the blackboard and explained using the picture and referring to the textbook.

Table 2

The lesson plan on Archimedes' principle (buoyancy force) in fluids when using traditional instruction

Lesson 1: 1 hour.

Learning goals

Students will be able to do the following:

- Describe Archimedes' principle.
- Explain buoyancy force.
- Describe the interaction between pressure, and Archimedes' principle (buoyancy force).
- Know about physical quantities such as pressure P, volume V, and force F.
- Demonstrate the applications of Archimedes' principle in real-life situations.

Phases	Traditional representation: Prescribed textbook: Serway and Jewett (2004, p. 395- 399)
Introduction	• Archimedes' principle. • Buoyancy. • The interaction between pressure, and Archimedes' principle.
Presentation	• Explain Archimedes' principle by talking, drawing diagrams and writing on the blackboard. • Show the interaction between pressure and Archimedes' principle on the blackboard using diagrams.
Summarisation	Summarise pressure and the relationship between pressure and Archimedes' principle.
Evaluation	Classwork was given and students reflected individually on the topic by completing the activity in their workbooks. A piece of wood is suspended from a string and then immersed in a container of water. • What will happen to the wood? • What will happen to the water height? • What will happen on reading spring balance? • Describe the relationship between pressure and Archimedes' principle (buoyancy force) in Figure 1. The teacher provides the correct answers so that students can record the correct answers.

Traditional instruction typically involves a lecture-style approach using methods such as chalk and talk (Chen & Gladding, 2014). Unfortunately, the traditional method does not offer students many opportunities to put into practice what they are learning (Mohammad, 2012).

3.3.3. Summary of lesson plans of the different iterations compared to the traditional instruction

There is almost no difference in the traditional intervention and the first iteration. In the traditional intervention, the teacher described and explained (verbal) while drawing the figures on the board (diagrams) when describing the Archimedes' principle. He then used mathematical equations to enhance student understanding of the relationships and ratios between physical quantities, such as changes in density and volume. The only difference between the first iteration and the traditional intervention was that the teacher used the figure from the textbook and displayed it on a screen as he used a computer and a screen and finally followed up with the PhET simulation that he projected on the screen.

In the second iteration the teacher still explained the concepts by means of text and words, the static pictures were replaced by animation pictures and a virtual lab and videos were used. Students had to discuss what would happen and then see what happened. They then had to explain what happened like all other students. More discussion was allowed since the time in class was better used. Rather than drawing pictures on the board, animations were shown, and the focus was shifted from only listing to active participation by the students discussing what they have seen. Therefore, in the second intervention, the multiple representations presented were in the form of contextual learning, including relating, experiencing, applying, cooperating, and transferring the concepts.

4. Results

The order in which the results are presented is starting with the t-tests using the pre-FMCI to establish if the two groups (experimental and control) were on the same level before any intervention, then ANCOVA to determine the effectiveness of the intervention. This was then followed by the analysis of the OEQ to verify the data on the effectiveness of the intervention quantitative and qualitatively as students had to include their reasoning.

4.1. Results from the Fluid Mechanics Conceptual Inventory (FMCI)

The pre- and post-test results for Intervention 1 and 2 are provided and compared with the control group (see Figure 9). Students' answers were categorised in the three conception models, M1, M2 and M3.

4.1.1. Intervention 1

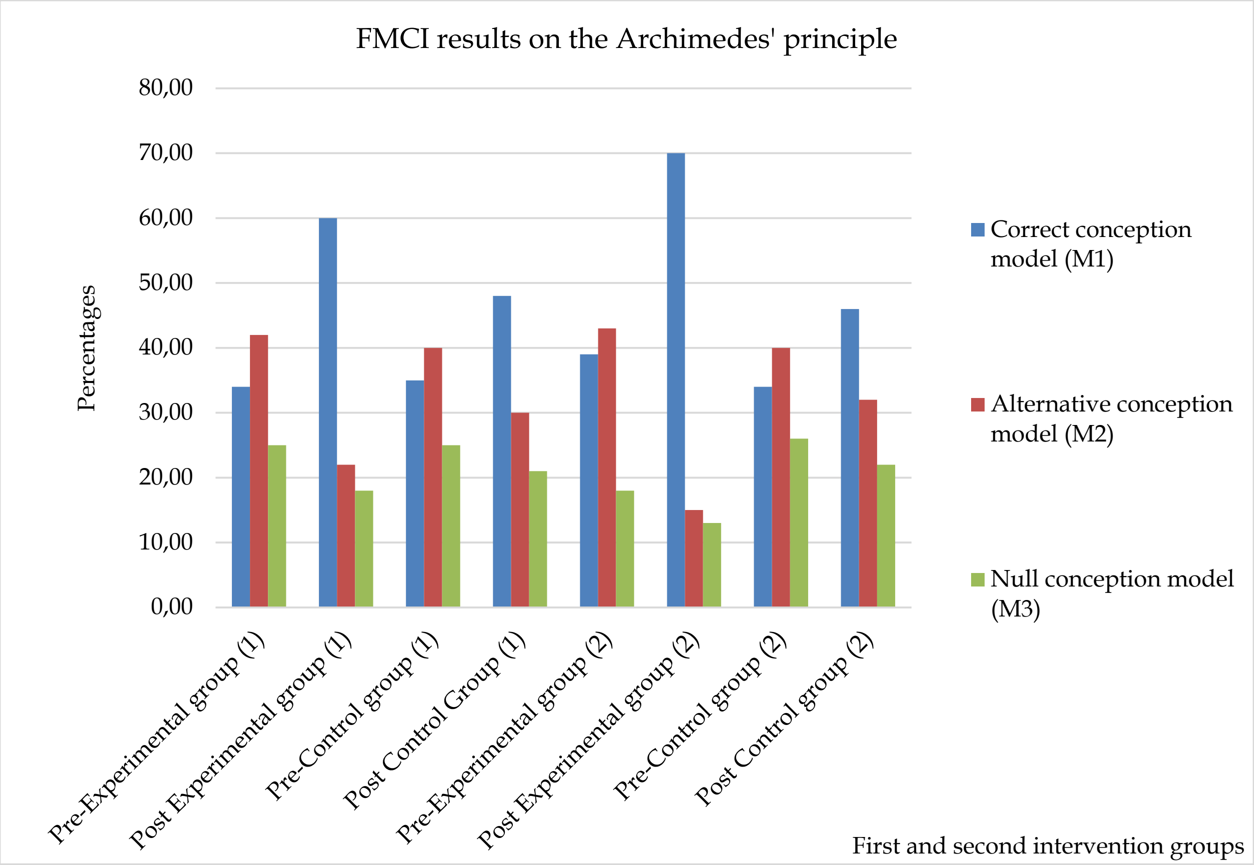
There was no difference in average results between the pre-experimental and -control groups or across the three groups categorised as M1, M2, and M3. The pre-experimental and pre-control groups did not differ significantly between M1, M2, and M3 ($t(31) = -0.623$, p-value .538 (where $p > .05$ at two-tailed); $t(31)=0.868$, p-value .392 (where $p > .005$ at two-tailed); $t(31)=-0.469$, p-value .642 (where $p > .005$ at two-tailed) respectively.

Results from the post-experimental and -control groups indicated that M1 was not statistically different with $t(31) = 1.43$, p-value 0.161 at the 95% confidence interval. The MR approach failed to show an absolute difference between the experimental and control groups. The results for the M2 and M3 groups were not statistically significant. At the 95% confidence interval of the difference, the results were $p > .005$ (two-tailed); t = 1.71, p-value .097, which is $p > .005$ (two-tailed); and t-value was -0.57, p-value .572, which is $p > .005$ (two-tailed).

Results from ANCOVA indicated there was no significant difference between the experimental and control groups, $F(1, 63) = 2.940$, $p = .027$. Although the MR approach contributed somewhat to addressing students' alternative conceptions compared to the control group, that is, there was a slight shift towards M1 away from M2 and M3, but the effect size was not significant to determine its effectiveness.

Figure 9

Pre- and post-test results from the FMCI after Intervention 1 and 2 respectively



4.1.2. Intervention 2

There was no statistically significant mean difference for the pre- experimental and -control groups before the intervention. The similarity of the results in the pre-tests for all three groups is: for M1 at $t(31)=-0.297$, p-value 0.768, which is $p>.000$ (two-tailed); for M2 at $t(31)=0.528$, p-value .601, which is $p>.000$ (two-tailed), and for M3 at $t(31)=-2.154$, p-value 0.039, which is $p>.000$ (two-tailed). The results in the pre-test for Iteration 2 were similar to Iteration 1 pre-test 1 and in both cases, there was no statistically significant mean difference.

There was a statistically significant mean difference between the two groups in the results from the post-experimental and -control groups: M1 at $t(31)=7.927$, p-value .0005 (two-tailed), which is .000; M2 at $t(31)=-4.101$, p-value 0.000, which is p 0.005 (two-tailed); and M3 at t $(31)=-4.73$, p-value .000, which is p .005 (two-tailed). The results of Iteration 1 did not show any statistical significance in comparison to M2 and M3. These results indicated that the experimental and control groups were $p>.005$ (two-tailed); $t=-1.714$, p-value 0.097; and $t=-0.571$, p-value .572, respectively, which indicates $p>.005$.

ANCOVA was used to compare the scores of the two groups (experimental and control) after Intervention 2. There was a significant difference between the two groups' FMCI scores, $F(1, 63)=0.447$, $p=.000$ (partially squared eta squared value for the effect size of 0.447). The partial eta squared value for the effect size for Intervention 2 had a greater effect size. In Intervention 1, the FMCI score was $F(1, 63)=0.294$, $p=.000$ (partial eta squared value for the effect size of 0.294).

In Iteration 1, six MRs were used. While the MR approach contributed somewhat to students' alternative conceptions compared to the control group, that is, some students shifted from M2 and M3, the effect size was not substantial enough to confidently claim the approach's efficacy in the experimental group.

In Iteration 2, a total of eight modes of representation (MR) were employed, incorporating a greater range of technologies. The MR approach contributed to addressing students' alternative conceptions, as students shifted from category M3 and M2 to category M1 and had an effect size of 0.294 which is considered a large effect size. The study proved that using eight technology enhanced representations in teaching fluid mechanics was more effective in addressing students' alternative conceptions after analysing the FMCI.

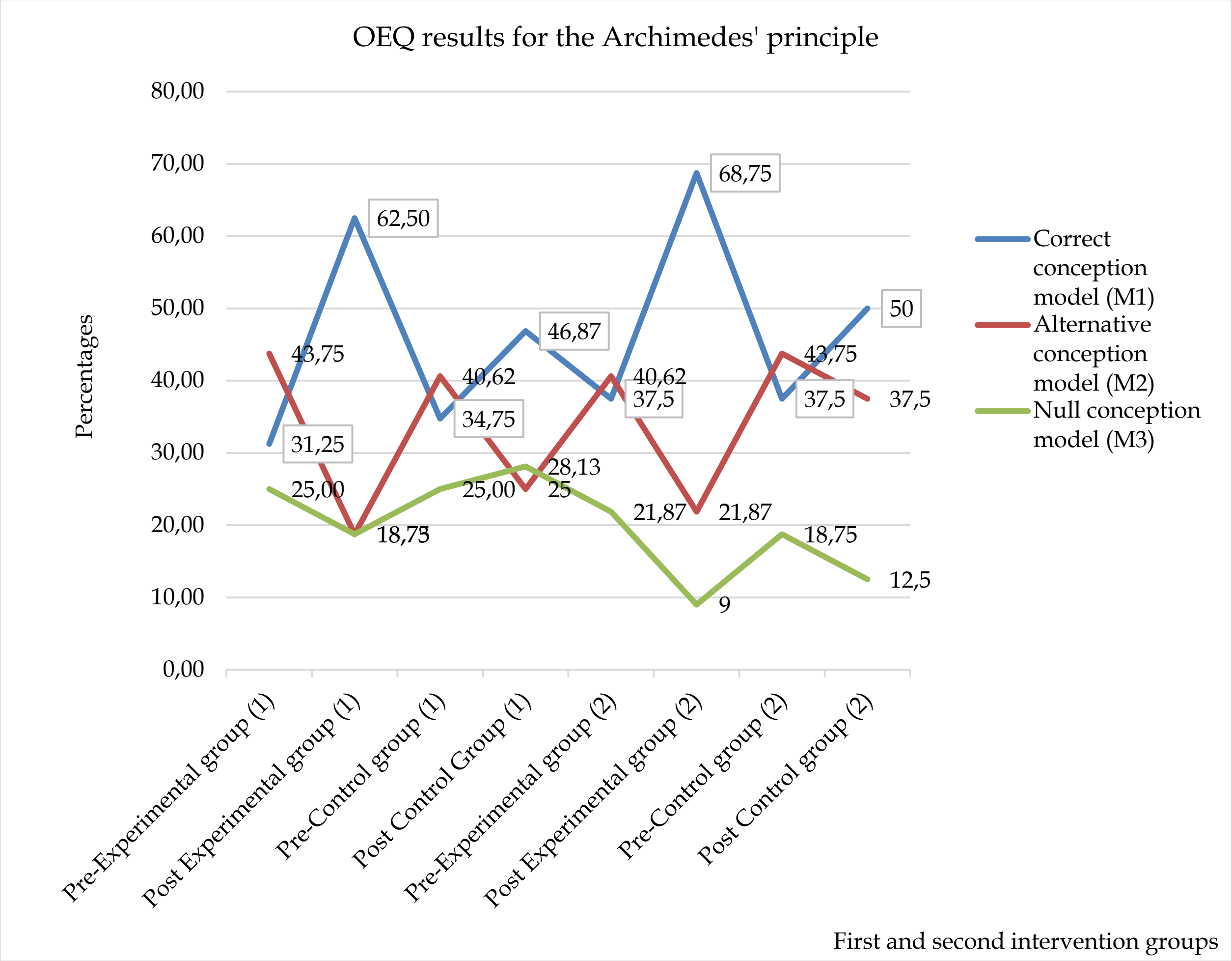
4.2. Results from Open-Ended Questionnaire (OEQ)

4.2.1. Quantitative results from the OEQ

The pre- and post-test results for Intervention 1 and 2 are provided using the quantitative part of OEQ (see Figure 10) and compared with the control group. Once again student answers were grouped into the three conception models.

Figure 10

Pre- and post-test results from the OEQ after Intervention 1 and 2



Intervention 1. The OEQ results of the pre-control and experimental groups are similar. In post-Intervention 1, a 15.63% difference was noted in students' correct answers (M1) in the experimental group compared to the control group. The result of M2 shows the control group exceeding the experimental group by 6.87% and a difference from the result of the pre-OEQ. Furthermore, the scores in M3, the control group, exceeded the experimental group by 9.38%, and there was a difference with the result of the pre-OEQ.

Intervention 2. Before the second intervention, there was no difference in M1 in the experimental group compared to the control group. Furthermore, the experimental group exceeded the control group by 3.13%, whereas in M3, the experimental group exceeded the control group by 3.13%. After the second intervention, there was an 18.75% greater student response in the M1 experimental group than in the control group. Besides, in Iteration 2, the M2 in the experimental group was 15.63% fewer than in the control group. Moreover, in M3, the experimental group was 3.50% fewer than the control group. This result had a greater difference than in Iteration 1.

4.2.2. Qualitative results from the OEQ

A qualitative analysis on students' understanding of the Archimedes' principle was done using student reasoning. In Table 3 the results of the first intervention with six MRs are presented while in Table 4 the results of the second intervention with eight MRs are provided.

Based on the qualitative analysis, students demonstrated a better understanding after the second iteration compared to the first iteration. This can be seen by an increase in the quality of responses aligned with the correct conceptual model. However, unfortunately there were still a number of students that even after the second intervention did not understand Archimedes' principle, however, when comparing the quantitative analysis there was a shift from M3 towards M2, to provide a better understanding (M1).

5. Discussion

The results indicated that before Intervention 1 and 2, approximately 40% of these undergraduate physics students had a correct understanding of the Archimedes' principle. From this data it is evident that the dominant category of students' understanding of the Archimedes' principle was in the alternative to null conception model.

Data from the instruments indicated that students had difficulty analysing the findings of the tasks and drawing conclusions once they had solved them. For example, when a substance was partially or completely submerged in a fluid, students found it challenging to appropriately analyse and perform mathematical computations; this was also found by Heron et al. (2003). When students had to explain the difference between the weight and density of the body inserted into a fluid, they became confused and these findings supported previous findings that students could not tell the difference between density and volume (Hewitt, 1990) and could not distinguish between the mass and volume of a substance immerged into a fluid (Loverude et al., 2010). Furthermore, students struggled to distinguish between Archimedes' principle (buoyancy force) and pressure; this was also found by other researchers (Wagner et al., 2009).

Undergraduate students have diverse notions of buoyancy force (Faour & Ayoubi, 2018; Raissi et al., 2020). This could be due to the fact that learners in high school too have difficulty with Archimedes' principle. In a study conducted to determine high school learners' understanding of Archimedes' principle, researchers found that learners, for example, had difficulty distinguishing hydrostatic pressure from Archimedes' ideas (Kafiyani et al., 2019).

Furthermore, Rosyidah et al. (2020) found that high-ability students remembered and could apply the concepts when objects were floating and sinking, while low-ability students did not remember the concept of the Archimedes force including the requirements of the objects floating and sinking. This shows that low-ability students still have difficulty in understanding the Archimedes force concept while this of course has an impact on students' critical thinking processes, especially when they had to explain the concept. Our findings concur with that of Rosyidah et al. (2020) who indicated that low-ability students were not able to provide correct reasons and conclusions with regard to the Archimedes' principle. This is because students were misled by the size of the volume of different objects. High-ability students usually understand that when an object is cut into pieces, its density will remain the same as the density of the object before it is cut. Low-ability students know that when an object is cut its volume and its mass will change but they usually think the ratio of the density of objects before and after being cut differs. This is the main cause of mistaken conclusions made by students of low ability. A recommendation is that teachers need to identify students' challenges so that they can provide the necessary scaffolding that is appropriate for them (Koes-H et al., 2018).

Table 3
Qualitative analysis after Intervention 1 on the Archimedes' principle

Iteration 1	*Pre-results of qualitative data on the Archimedes' principle*	*Post-results of qualitative data on the Archimedes' principle*
Correct conception model (M1)	The volume of an object immersed in a fluid equals the volume of displaced water. The volume of displaced water is related to the volume of the inserted object. The buoyancy force is proportional to the trust pressure.	The buoyancy force is the opposite of the weight of an object. Buoyancy force equals trust pressure. The buoyancy force is equal to the pressure in the ascending direction. The object is partially immersed in a fluid due to the buoyancy force.
Alternative conception model (M2)	Boundary pressure equals buoyancy force. The buoyancy force is a natural force that exists within the body. The buoyancy force is volume.	A buoyancy force equals a pressure force. The buoyancy force equals the volume of an object. An object's buoyancy force is equal to its opposing weight. The magnitude of the buoyancy force is always greater than the weight of the fluid displaced by the object.
Null conception model (M3)	The buoyancy force is equal to the mass of an object. The buoyancy force of an object equals its weight.	The objects instated in the water have no buoyancy force. The buoyancy force of an object is equal to its pressure.

Table 4
Qualitative analysis after Intervention 2 on the Archimedes' principle

Iteration 2	*Pre-results of qualitative data on the Archimedes' principle*	*Post-results of qualitative data on the Archimedes' principle*
Correct conception model (M1)	The buoyancy force is the pressure that implies internal forces. The volume of an object is equal to the volume of displaced water. A buoyancy force is the upward force exerted by a fluid on any immersed object. The buoyant force is the resultant force due to all forces applied by the fluid surrounding it.	The displacement of water volume in a fluid change in relation to the volume of the inserted object. The volume of a submerged object is equal to the volume of overflowing water. In equilibrium, there must be an upward force that balances the downward gravitational force. The upward force is the buoyant force, and its magnitude is equal to the weight of the water. The resultant force applied by the surrounding fluid is the same for all.
Alternative conception model (M2)	The buoyancy force is equal to the pressure The buoyancy force is related to the weight of an object. The buoyancy force is the resistance force applied to the inserted object. The buoyancy force has only magnitude but have no direction	The buoyancy force is the force that attracts the inserted object in a fluid. If the object is totally immersed in a fluid, there is no buoyancy force in the fluid. The buoyancy force is different from the fluid pressure. The buoyancy force is directly related to the inserted object's weight.
Null conception model (M3)	The buoyancy force is equal to the volume of an object. The buoyancy force is equal to the mass of an object. The buoyancy force is always positive	There is no buoyancy force in a fluid at all. The buoyancy force is perpendicular to the object. The buoyancy force is a scaler physical quantity. The SI unit of the buoyancy force is Newton.

Finally, we can concur with the findings of Volkwyn et al. (2020) that highlight the challenges students face in meaningfully connecting various forms of representation within a given task or problem, as well as in extracting the intended conceptual understanding. However, it is anticipated that the use of a multi-exposure representation of science in physics education will enhance students' ability to solve physics problems effectively (Munfaridah at al., 2021).

7. Contributions

Previous studies indicated that three to four MRs were used effectively (Hartini & Sinensis, 2019), for example, Faour and Ayoubi (2018) used only three representations and did not try to improve them or add other representations at another time. This study contributes to the facilitation of students' conceptual understanding in basic physics, using eight MRs. However, the focus must not be on the number of representations but rather on the combination of the MRs. The use of a combination of technology-enhanced representations was found to be effective. The MRs must be used in context, and it is necessary to apply a concept in different situations by comparing for example a ring of gold and a block of gold (see Figure 4 & 5) and transferring a concept to other situations by, for example, comparing the crowns (see Figure 7).

The study was found to be effective where the lecturer was manipulating the videos and simulations while creating an interactive environment.

8. Recommendations

When using the MR approach, eight or more different representations need to be added as they can address students' different variations of intelligence (e.g., visual, words). These also provide different contexts and provide opportunities for the students to transfer their understanding to these different contexts. Other topics and various levels (primary school, high school, or university) need to be explored using the MR approach.

When implementing any teaching sequence, research needs to be done to establish its effectiveness. If the teaching sequence is not effective, changes to the approach need to be made until conceptual understanding is facilitated.

9. Conclusion

In the first intervention, pictures, diagrams, equations, and simulations were presented on a screen minimising the need for writing on the blackboard and saving time. However, despite these efforts, it did not significantly improve students' understanding. In the second intervention, representations using text, animated pictures, diagrams, mathematical equations, simulations, animation videos, and virtual labs were incorporated. In this case there was a notable improvement in student understanding. By efficiently utilising the time that would have been spent writing and explaining on the blackboard, meaningful discussions between lecturer and students as well as among students themselves could be facilitated. Consequently, time was used more effectively allowing for the application of concepts to new situations, enhancing the learning experience.

MRs can be used to support contextual learning in basic physics as it addresses the visual and auditory senses in a unique manner. However, only presenting different MRs is not the sole answer, one needs to carefully select the appropriate technology in the form of animation pictures, videos, and virtual labs, as in this way contextual learning can be facilitated by students having to relate the various concepts, applying it in different situations and transferring them to different situations. The findings indicate that it is not only the number of MRs but how these are incorporated in the teaching and learning of basic physics that will facilitate proper conceptual understanding.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Declaration of interest: No conflict of interest is declared by authors.

Ethics declaration: Ethical approval was granted by the Ethics sub-committee of the College of Science Engineering and Technology at the University of South Africa with the code 2014_CGS/ISTE_009 on 11.9.2014.

Funding: No funding source is reported for this study.

References

Abdurrahman, A., Setyaningsih, C. A. & Jalmo, T. (2019). Implementing a multiple representation-based worksheet to develop critical thinking skills. *Journal of Turkish Science Education, 16*(1), 138-155.

Airey, J., Lindqvist, J. G. & Kung, R. L. (2019). What does it mean to understand a physics equation? A study of undergraduate answers in three countries. In E. McLoughlin, O. E. Finlayson, S. Erduran, & P. E. Childs (Eds.), *Bridging Research and Practice in Science Education: Selected Papers from the ESERA 2017 Conference* (pp. 225-239). Springer. https://doi.org/10.1007/978-3-030-17219-0_14

Bakó-Biró, Z., Clements-Croome, D. J., Kochhar, N., Awbi, H. B. & Williams, M. J. (2012). Ventilation rates in schools and students' performance. *Building and Environment*, *48,* 215-223. https://doi.org/10.1016/j.buildenv.2011.08.018

Bao, L., & Redish, E. F. (2006). Model analysis: Representing and assessing the dynamics of student learning. *Physical Review Special Topics-Physics Education Research*, 2(1), 010103. https://doi.org/10.1103/PhysRevSTPER.2.010103

Bicer, A. (2021). Multiple representations and mathematical creativity. *Thinking Skills and Creativity*, *42*, 100960. https://doi.org/10.1016/j.tsc.2021.100960

Bussey, T. J., Orgill, M. & Crippen, K. J. (2013). Variation theory: A theory of learning and a useful theoretical framework for chemical education research. *Chemistry Education Research and Practice*, *14*(1), 9-22. https://doi.org/10.1039/C2RP20145C

Chen, Z., & Gladding, G. (2014). How to make a good animation: A grounded cognition model of how visual representation design affects the construction of abstract physics knowledge. *Physical Review Special Topics-Physics Education Research*, *10*(1), 010111. https://doi.org/10.1103/PhysRevSTPER.10.010111

de Cock, M. (2012). Representation use and strategy choice in Physics problem-solving. *Physical Review Special Topics-Physics Education Research, 8*(2), 1–15. https://doi.org/10.1103/PhysRevSTPER.8.020117.

Diyana, T. N., Sutopo, S. & Haryoto, D. (2020). The study of students' difficulties in mastering the concept of Archimedes' principle. *Jurnal Pendidikan Sains Universitas Muhammadiyah Semarang*, *8*(1), 59-65. https://doi.org/10.26714/jps.8.1.2020.59-64

Eichenlaub, M. & Redish, E. F. (2019). Blending physical knowledge with mathematical form in Physics problem-solving. In G. Pospiech, M. Michelini, & B. S. Eylon (Eds.), *Mathematics in Physics Education* (pp. 127-151). Springer. https://doi.org/10.1007/978-3-030-04627-9_6

Euler, E., & Gregorcic, B. (2018, July). *Discovering variation: learning Physics in a creative digital environment* [Paper presentation]. European Association for Research on Learning and Instruction (EARLI) Conference, Belgium.

Faour, A. M., & Ayoubi, Z. (2018). The effect of using virtual laboratory on grade 10 students' conceptual understanding and their attitudes towards physics. *Journal of Education in Science Environment and Health*, *4*(1), 54-68.

Franke, K., Chagas, A. M., Zhao, Z., Zimmermann, M. J., Bartel, P., Qiu, Y. & Euler, T. (2019). An arbitrary-spectrum spatial visual stimulator for vision research. *Elife*, *8*, e48779. https://doi.org/10.7554/eLife.48779.024

Fredlund, T., Airey, J. & Linder, C. (2015). Enhancing the possibilities for learning: variation of disciplinary-relevant aspects in Physics representations. *European Journal of Physics, 36*, 055001. https://doi.org/10.1088/0143-0807/36/5/055001

Gestson, S. L., Lutz, B., Brown, S., Barner, M. S., Hurwitz, D. & Abadi, M. (2018). Developing an understanding of civil engineering practitioner problem-solving rationale using multiple contextual representations. *ASEE Annual Conference & Exposition*, *1,* 23100. https://doi.org/10.18260/1-2--30301

Geyer, M. A. & Kuske-Janßen, W. (2019). Mathematical representations in Physics lessons. In G. Pospiech, M. Michelini, & B. S. Eylon (Eds.), *Mathematics in Physics Education* (pp. 75-102). Springer. https://doi.org/10.1007/978-3-030-04627-9_4

Hartini, T. I. & Sinensis, A. R. (2019). The effectiveness of thermodynamic learning is based on multiple representations toward understanding the basic concepts of physical education students. *Journal of Physics: Conference Series*, *1157*, 032043. https://doi.org/10.1088/1742-6596/1157/3/032043

Hartini, T. I., Liliasari, S., Agus, S. & Ramalis, R. (2020). Creating an analytical mechanics course programme that is based on Geogebra multiple representations (Mgeo-MR). *Journal of Physics: Conference Series, 1572*, 012015. https://doi.org/10.1088/1742-6596/1572/1/012015

Heron, P. R., Loverude, M. E., Shaffer, P. S., & McDermott, L. C. (2003). Helping students develop an understanding of Archimedes' principle. II. Development of research-based instructional materials. *American Journal of Physics*, *71*(11), 1188-1195. https://doi.org/10.1119/1.1607337

Hewitt, P. G. (1990). Conceptually speaking: teaching the physics concepts before introducing the formulas. *Science Teacher*, *2*, 55-57.

Jewett, J. W., & Serway, R. (2008). *Physics for scientists and engineers with modern physics.* Cengage Learning.

Kafiyani, F., Samsudin, A., & Saepuzaman, D. (2019). Development of four-tier diagnostic test (FTDT) to identify student's mental models on static fluid. *Journal of Physics: Conference Series*, *1280*(5), 052030. https://doi.org/10.1088/1742-6596/1280/5/052030

Koes-H, S., Muhardjito, M., & Wijaya, C. P. (2018). Scaffolding for solving problem in static fluid: A case study. *AIP Conference Proceedings, 1923*(1), 030028. https://doi.org/10.1063/1.5019519

Kohl, P. B. & Finkelstein, N. D. (2006). Effects of representation on students solving Physics problems: A fine-grained characterization. *Physical Review Special Topics-Physics Education Research*, *2*(1), 010106. https://doi.org/10.1103/PhysRevSTPER.2.010106

Loverude, M. E., Heron, P. R. L., & Kautz, C. H. (2010). Identifying and addressing student difficulties with hydrostatic pressure. *American Journal of Physics*, *78*(1), 75-85. https://doi.org/10.1119/1.3192767

Loverude, M. E., Kautz, C. H. & Heron, P. R. (2003). Helping students develop an understanding of Archimedes' principle. I. Research on student understanding. *American Journal of Physics*, *71*(11), 1178-1187. https://doi.org/10.1119/1.1607335

Martin, J., Mitchell, J. & Newell, T. (2003, November). *Development of a concept inventory for fluid mechanics* [Paper presentation]. *Proceedings of the 33rd ASEE/IEE Frontiers in Education Conference*, Boulder, CO, USA.

Martínez, B. & Rebello, N. (2012). Representational task formats and problem-solving strategies in kinematics and work. *Physical Review Special Topics: Physics Education Research, 8*(1), 010126. https://doi.org/10.1103/PhysRevSTPER.8.010126

Michael, J. & Modell, H. I. (2003). *Active learning in secondary and college science classrooms: A working model for helping the learner to learn*. Routledge. https://doi.org/10.4324/9781410609212

Miller, P. H., Slawinski Blessing, J. & Schwartz, S. (2006). Gender differences in high-school students' views about Science. *International Journal of Science Education*, *28*(4), 363-381. https://doi.org/10.1080/09500690500277664

Minichiello, A., David, A., Sarbajit, M., Lori, C., Vladimir, K., Tadd, T. & Aditya, B. (2020). Developing a mobile application-based particle image velocimetry tool for enhanced teaching and learning in fluid mechanics: A design-based research approach. *Computational Applied Engineering Education*, *29,* 517–537. https://doi.org/10.1002/cae.22290

Mohammad, M. (2012). The impact of e-learning and e-teaching. *International Journal of Educational and Pedagogical Sciences*, *6*(2), 229-234.

Munfaridah, N., Avraamidou, L., & Goedhart, M. (2021). The use of multiple representations in undergraduate physics education: what do we know and where do we go from here?. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(1), em1934. https://doi.org/10.29333/ejmste/9577

Raissi, M., Yazdani, A., & Karniadakis, G. E. (2020). Hidden fluid mechanics: Learning velocity and pressure fields from flow visualizations. *Science*, *367*(6481), 1026-1030. https://doi.org/10.1126/science.aaw4741

Rosyidah, N. D., Kusairi, S., Taufiq, A. & Affriyenni, Y. (2020). Profile of students' critical thinking processes on the topics of Hydrostatic Pressure and Archimedes' principle. *Journal of Physics: Conference Series*, *1511*(1), 012081. https://doi.org/10.1088/1742-6596/1511/1/012081

Serway, R. A., & Jewett, J. W. (2004). *Physics for scientists and engineers.* Thomson Brooks.

Volkwyn, T. S., Airey, J., Gregorcic, B. & Linder, C. (2020). Developing representational competence: linking real-world motion to Physics concepts through graphs. *Learning: Research and Practice, 6*(1), 88–107. https://doi.org/10.1080/23735082.2020.1750670

Wagner, D. J., Cohen, S., & Moyer, A. (2009, November). Addressing student difficulties with buoyancy. *AIP Conference Proceedings, 1179*(1), 289-292. https://doi.org/10.1063/1.3266739