

Characterization of Science Teachers' Teaching Practices Using Pedagogical
Content Knowledge Perspectives in a Developing Country with a Highly
Centralized Education System

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Dedication

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Abstract

This study aimed to understand Malaysian physics teachers' teaching practices from a pedagogical content knowledge (PCK) perspective. The physics topic of interest was Archimedes' principle. A multiple-case study approach was used, and classroom teaching observations and audio records of teaching, interviews, and collection of documents were the data sources on the teachers' teaching practices and their knowledge about their practices. This study found that two national contextual amplifiers, the national assessment and curriculum, were strongly associated with the teachers' PCK in practice. Their uses of teaching activities and representations were mostly consistent with these two national contextual amplifiers. Nonetheless, the teachers had freedom to choose and use any teaching activities and representations that they deemed appropriate for students, demonstrating the personal nature of their PCK in practice. This study suggests that the national curriculum is a source of canonical PCK because the official curriculum directly informed the teachers about the subject matter of teaching Archimedes' principle, and it is a nationwide curriculum sanctioned by the Ministry of Education. The main recommendation from this study is for the Ministry of Education to consider changing the national contextual amplifiers in order to transform science teachers' PCK in practice.

Table of Contents

Acknowledgements.....	i
Dedication.....	ii
Abstract.....	iii
List of Tables.....	vii
List of Figures.....	viii
Chapter I: Introduction.....	1
Overview.....	1
The Degree of Standardization of Curriculum and Assessment across Some Developed Nations.....	3
Pedagogical Content Knowledge.....	5
Pedagogical Content Knowledge in Practice.....	7
The Physics Subject.....	8
Potential Significance.....	8
Definitions of Main Terms.....	9
Chapter II: Literature Review.....	14
Overview.....	14
The Practices of Physics Teachers Using Standardized Curriculum and Assessment.....	15
Conceptions of PCK.....	17
Issues in PCK.....	21
Conceptual Framework.....	24
Studies of PCK in Practice.....	29

Studies on Archimedes' Principle.....	33
Studies on Science Teaching Activities.....	35
Studies on Representations.....	39
Studies on Amplifiers and Filters.....	42
Qualitative Research: Case Study Design.....	44
Methodological Aspects of Capturing PCK in Practice.....	46
Chapter III: Research Methods.....	52
Research Paradigm.....	52
Contexts.....	52
Research Design.....	59
Participant Selection.....	61
Conceptual Framework.....	63
Data Collection.....	64
Data Analysis and Validation.....	71
Background and Roles of the Researcher.....	84
Chapter IV: Single Case Analysis.....	87
Case I: Aminah.....	87
Case II: Aishah.....	139
Case III: Ali.....	217
Chapter V: Cross-case Analysis.....	276
How Do Physics Teachers Teach Archimedes' Principle in Real Classroom Settings?.....	276

Why Do Physics Teachers Teach Archimedes' Principle in the Ways They Do?.....	286
Chapter VI: Themes, Discussion, Conclusion, and Recommendations.....	303
Themes and Discussion.....	304
Conclusion.....	317
Recommendations for Policy, Practice, and Future Research.....	318
Final Remarks.....	325
References.....	327
Appendix A.....	341
Appendix B.....	346
Appendix C.....	351

List of Tables

Table 1 <i>Numerous Conceptions of PCK</i>	19
Table 2 <i>National Curriculum Specifications on Archimedes' Principle for the Form Four Physics Curriculum (or Grade 11 Equivalent)</i>	55
Table 3 <i>Characteristics of Participants</i>	63
Table 4 <i>Timing of Data Collection</i>	65
Table 5 <i>Data Matrix</i>	70
Table 6 <i>Unique IDs for Codes</i>	75
Table 7 <i>Orders and Combinations of Teaching the Main Ideas</i>	278
Table 8 <i>Main Characteristics of the Teachers' Teaching Activities</i>	281
Table 9 <i>Translations of Representations of Idea A and Associated Ideas</i>	284
Table 10 <i>Reasons for Using Certain Teaching Activities</i>	293

List of Figures

<i>Figure 1.</i> The integrative PCK model.....	25
<i>Figure 2.</i> Idea A of Archimedes' principle.....	77
<i>Figure 3.</i> The weight of liquid displaced.....	78
<i>Figure 4.</i> An investigation of Archimedes' principle.....	93
<i>Figure 5.</i> A ship and Plimsoll lines.....	97
<i>Figure 6.</i> A simple hydrometer.....	99
<i>Figure 7.</i> A submarine and ballast tanks.....	100
<i>Figure 8.</i> Designing a boat.....	103
<i>Figure 9.</i> A group's answers.....	105
<i>Figure 10.</i> The weight of liquid displaced.....	107
<i>Figure 11.</i> A group's answers to the question regarding the weight of liquid displaced.....	109
<i>Figure 12.</i> A quantitative question about the application of Idea C, a hot air balloon.....	110
<i>Figure 13.</i> The group's answer to the quantitative problem on flotation (4 (a) and (b)).....	112
<i>Figure 14.</i> A question about designing a submarine.....	114
<i>Figure 15.</i> The group's answers of the submarine application.....	117
<i>Figure 16.</i> The investigation on the relationship between a buoyant force and the loss of weight of an object.....	143
<i>Figure 17.</i> The free-body diagram of the buoyant force and the weight of the object.....	146

<i>Figure 18.</i> The idea of the weight loss of an object in the water.....	148
<i>Figure 19.</i> The idea of the weight of water displaced.....	154
<i>Figure 20.</i> The weight of liquid displaced and the volume of liquid displaced.....	156
<i>Figure 21.</i> The volume of water displaced.....	158
<i>Figure 22.</i> The quantitative question on Idea B and Idea A.....	162
<i>Figure 23.</i> A quantitative question on Idea C regarding flotation.....	167
<i>Figure 24.</i> The quantitative question on Idea B and Idea A.....	170
<i>Figure 25.</i> The quantitative question on Idea A and Idea C.....	173
<i>Figure 26.</i> The quantitative question on Idea A and Idea B.....	177
<i>Figure 27.</i> The application of Idea C and Idea A – boats.....	181
<i>Figure 28.</i> The application of Ideas A and C – ships carrying loads.....	183
<i>Figure 29.</i> Plimsoll symbols on a ship.....	186
<i>Figure 30.</i> The application of immersion, submarines.....	188
<i>Figure 31.</i> The application of flotation, hot air balloons.....	190
<i>Figure 32.</i> The application of hydrometer.....	192
<i>Figure 33.</i> Idea A of Archimedes’ principle.....	220
<i>Figure 34.</i> The weight of liquid displaced.....	221
<i>Figure 35.</i> Factors influencing the buoyant force.....	223
<i>Figure 36.</i> Idea C regarding flotation.....	225
<i>Figure 37.</i> Idea C regarding flotation applied to a ship.....	226
<i>Figure 38.</i> Ideas of flotation and immersion.....	229
<i>Figure 39.</i> Applications of flotation and immersion.....	229

<i>Figure 40.</i> The application of immersion, a submarine’s ballast tank.....	232
<i>Figure 41.</i> The application of flotation, hot air balloons.....	234
<i>Figure 42.</i> The application of hydrometers.....	236
<i>Figure 43.</i> Written notes on Idea A.....	239
<i>Figure 44.</i> The weight loss of an object.....	241
<i>Figure 45.</i> A floating object.....	243
<i>Figure 46.</i> A quantitative question on Idea A.....	244
<i>Figure 47.</i> The question on the application of hot air balloons.....	249
<i>Figure 48.</i> The question about submarines, the application of Idea D.....	253
<i>Figure 49.</i> The question about a boat.....	258

Chapter I: Introduction

Overview

Science educators around the world have always been interested in improving their teaching practices. The notion of pedagogical content knowledge (PCK) in practice could be used to understand science teachers' practice of teaching where PCK integrates knowledge bases for teaching a specific topic. Initially, PCK was conceptualized as a blend of teachers' knowledge of subject matter and pedagogy (Shulman, 1986), but the way PCK has been conceptualized and studied has done little to connect teachers' knowledge with practice. Shulman (2015) acknowledged that the initial PCK concept he had proposed (Shulman, 1986) did not emphasize teachers' practices and urged researchers to study contextual factors that could inform teachers' PCK in practice. Kind (2015) also mentioned that inclusion of contextual knowledge into PCK constructs was uncommon, but only a few PCK studies have explicitly considered contextual knowledge (e.g., Fernandez-Balboa & Stiehl, 1995).

The objective of this study was to describe the teaching practices of physics teachers in Malaysia, a developing country with a highly centralized educational system where the national curriculum and assessment are standardized nationwide for the upper secondary education. More specifically, the study attempted to describe how physics teachers teach and why they teach as they do. The physics topic for this study was Archimedes' principle because it is a high-level topic that is challenging for students to understand (She, 2002).

The two research questions were:

- (1) How do physics teachers teach Archimedes' principle in real classroom settings?
- (2) Why do physics teachers teach Archimedes' principle in the ways they do?

The descriptions that answered these questions were developed in terms of the teachers' pedagogical content knowledge (PCK) in practice. PCK in practice relates to how teachers' subject matter knowledge, pedagogical knowledge, contextual knowledge, and their integrations relate to teachers' teaching practices and the reasons for those practices.

The results of the study can contribute to the literature on PCK in practice in several ways. Specifically, it examined the type of PCK of "as it is" or PCK at a specific point in time (versus the development of teachers' PCK using particular interventions) because research on this PCK type is still in the early phases (Van Driel, Berry, & Meirink, 2014). The findings could also be used to improve educational policies and practices in a highly centralized education system such as in Malaysia. Finally, teacher education programs could be informed that prospective teachers should be told about the reality of teaching science in a country that practices a highly centralized education system, so they can be best prepared.

The Degree of Standardization of Curriculum and Assessment across Some Developed Nations

One main feature of Malaysia's educational system is the practice of a highly standardized curriculum and a nationwide assessment system for the upper secondary level. The Ministry of Education sets a single curriculum of physics (and other subjects) and teachers are required to teach the specific topics outlined in the curriculum. For the assessment, each student completes a national physics exam with questions created by the Ministry of Education and all students answer the same questions in a particular year.

Across the globe, countries like Australia, the United Kingdom, the United States, and the Netherlands have somewhat different degrees of standardization. Australia, for example, has a national curriculum, but its educational assessment system is more decentralized where each state and territory is given a mandate to run its own assessment of students (Australian Curriculum, Assessment, and Reporting Authority, 2016).

The United Kingdom has a national curriculum and a national exam (General Certificate of Secondary Education), but its educational assessment is not standardized nationwide. The national exam is conducted by five exam boards that are mostly regional. Schools can choose specific exam boards for the national assessment. The exam boards are regulated by the UK government, but are independent organizations.

The Netherlands also has a national curriculum, but its assessment is partly school-based where scores from school assessment are combined with the national exam results (National Center on Education and Economy, 2017). In contrast, the United States has no national curriculum or nationwide assessment. Overall, these developed countries have generally adopted a national curriculum (except the United States), but their assessment systems are not standardized, making them very different from Malaysia where a national curriculum and nationwide assessment is mandated.

Au (2007) studied the roles of standardized testing in shaping teachers' practices based on studies on the effect of standardized testing in the United States. Au found that standardized testing has a strong influence on teachers' practices even though the US practices a decentralized system with no national exam for the secondary school students. Although Au specifically reviewed the US, the review implies that a national exam might have a greater influence over teachers' teaching practices. Au's findings motivated this study to consider the national examinations as a part of the context that might influence teachers' practices of teaching. Along with the national exam, the national curriculum factors were also included because the official curriculum might have an association with the national exam since the Ministry of Education controls both factors. Effects of the national assessment and curriculum on teachers' teaching practices were examined using the notion of PCK in practice including subject matter, pedagogy, and contexts.

Pedagogical Content Knowledge

The major premise of this study is that our understanding of teaching practices can be informed by research using the notion of pedagogical content knowledge (PCK), specifically PCK in practice. Shulman (1986) originally introduced PCK and argued that science teachers should be able to transform their subject matter knowledge into subject matter knowledge for teaching. In other words, teachers must be able to select and organize the main ideas of science that are relevant and appropriate to their students at a particular level. Thus, teachers must use their own PCK to decide what will be taught and how the teaching will be done in practice. Teachers with well-developed PCK can sequence the delivery of scientific knowledge appropriately to meet specific students' needs in specific teaching situations.

PCK is unique knowledge that distinguishes teachers from other professionals. It suggests that teachers need to have strong subject matter knowledge, pedagogical knowledge, and contextual knowledge (Gess-Newsome, 1999), and that these three forms of knowledge must be integrated for teachers to be effective. The Gess-Newsome model was used in this study because the three components of the model (i.e., the three forms of knowledge) were expected to be essential in understanding teachers' practices and because the model required integration of the three knowledge bases.

Subject matter knowledge is essential for effective teaching. Teachers who lack subject matter knowledge tend to have alternative conceptions that are

similar to those of their students (Burgoon, Heddle, & Duran, 2010) and there is a risk that the students' alternative concepts could be reinforced if teachers do not have strong subject matter backgrounds. A strong subject matter background also plays a critical role in building teachers' confidence in teaching science (Childs & McNicholl, 2007).

Enhancing teachers' subject matter knowledge alone is not enough to produce effective teaching; pedagogical knowledge is needed as well. Studies show that just improving teachers' subject matter knowledge does not automatically increase their ability to teach effectively (Van Driel et al., 2014). Teachers need to have a repertoire of teaching activities that may fit with the particular subject matter such as complex ideas found in science. For instance, teaching students about the physics concept of buoyancy requires teachers to use multiple teaching activities such as physical models, lab work, and discussion (Loverude et al., 2003; Heron et al., 2003). Simply lecturing students about buoyancy is not sufficient because the concept is abstract and an effective teacher needs various strategies to teach it in comprehensible ways.

According to the integrative model of PCK (Gess-Newsome, 1999), context is also important. Teachers need to consider external factors that might affect their teaching practices like national and school factors. Taking into account contextual factors might be essential to ensure that the teaching is relevant to the students, schools, and nation.

This study included contextual knowledge in the PCK construct because specific contexts appeared to play an important role in shaping science teachers' practices in settings where teachers need to teach a national curriculum with a national assessment, as well as other more local contextual factors. Inclusion of contextual knowledge is not common in most PCK models (Kind, 2015).

Pedagogical Content Knowledge in Practice

Although numerous studies have examined science teachers' PCK, these studies typically have not focused on PCK in practice (Settlage, 2013). Instead, they have been largely independent of practice and typically examined what teachers believed was possible or practices they would intend to use. Settlage (2013) mentioned, "a key departure from PCK has been the attention given to teaching actions and teacher moves rather than solely on what teachers store in their heads" (p. 10). Focusing on PCK in practice is consistent with recent recommendations of other scholars (Henze & Van Driel, 2015).

This study examined science teachers' PCK in practice to understand what teaching activities and representations they chose from their repertoire and the reasons for their choices when faced with the realities of actual teaching. That is, studying PCK in practice can illuminate specific descriptions of the three primary PCK constructs – subject matter, pedagogy, and context – and integration of these knowledge bases in practice.

The Physics Subject

Since this study focuses on teaching science, more specifically physics, it was prudent to select a specific topic to examine teachers' PCK in practice. This study focused on teaching Archimedes' principle in physics classes. The topic was selected for the following reasons:

- (1) It is usually taught in physics courses around the world.
- (2) It is required and assessed by the Ministry of Education in Malaysia (Ministry of Education, 2005).

Teaching Archimedes' principle is a difficult aspect of physics instruction consisting of many high-level concepts (She, 2002), and teachers have reported having difficulty teaching this topic and needing more time to teach it (Mohd Salleh & Abdullah, 2008). Thus, examining how teachers teach buoyancy is an appropriate research case.

The researcher has a background in physics education that can help him understand this physics topic. In addition, he investigated the topic of buoyancy during his master's degree studies (for more background information, please refer to the researcher's roles in Chapter 3).

Potential Significance

The main direction of this study was to focus on the inclusion of contextual knowledge as one of the constructs of PCK along with other two knowledge bases, subject matter and pedagogical knowledge. This inclusion might reveal the influence of contextual factors on teachers' subject matter and

pedagogy in specific ways. Since PCK scholars have not commonly explored contexts, the study could contribute to understanding of the integration of three knowledge bases in practice “as it is,” and their possible intricacies. The primary contribution could be the effects of the national assessment and curriculum on science teachers’ pedagogical and subject matter knowledge in practice.

The Ministry of Education of Malaysia and school administrators could be informed that science teachers’ knowledge and practices might be quite influenced by contextual factors at the national or school levels. Thus, they could take action to amplify or moderate those factors to enhance teachers’ teaching practices. The Ministry of Education could also create policies that address those factors at the national level, while school administrators could take action at the local level.

The findings of the study can also be used as the basis for a larger scale study. For example, the findings could be verified by future studies with a larger sample to confirm the applicability of the findings to other research cases. Moreover, the findings of the study could inform science teacher educators about the nature of PCK in practice in a highly centralized education system. Hence, they could educate preservice science teachers about the reality of school science teaching in this type of system.

Definitions of Main Terms

The following definitions were used for planning and conducting this study.

Teaching practices are the physics teachers' goals of teaching Archimedes' principle, their teaching activities, and representations.

Pedagogical content knowledge (PCK) consists of three types of teacher knowledge, subject matter knowledge, pedagogical knowledge, and contextual knowledge, as well as the integrations of those three types of knowledge bases (Gess-Newsome, 1999).

PCK in practice refers to subject matter knowledge, pedagogical knowledge, and contextual knowledge, as well as the three two-fold and one three-fold integrations of these three types of knowledge bases that were used during actual classroom teaching.

Subject matter knowledge (SMK) consists of the teachers' physics ideas that were used to teach Archimedes' principle and the ways they organized the ideas in teaching. Archimedes' principle is the physics principle that explains the relationship between a buoyant force and the weight of liquid displaced using the formula of $F = V\rho g$ where F is the buoyant force, V is the volume of liquid displaced, ρ is the density of liquid displaced, and g is the gravitational acceleration.

Pedagogical knowledge (PK) consists of the teachers' teaching activities such as demonstrations, lab work, questioning, lecture, group work and discussion, and various representations of the ideas that make up Archimedes' principle.

Representations are the specific ways of portraying ideas of Archimedes' principle using eight modes: (1) verbal symbols, (2) written symbols, (3) formulae or equations, (4) manipulatives, (5) real-life situations, (6) pictures, (7) tables, and (8) graphs. These representations come from Lesh's translation model (Lesh & Doerr, 2003). Translations are the sequences of representations the teachers used during their teaching, across and within the eight modes. Verbal symbols (VS) representations are oral-based action that a teacher could use to explain Archimedes' principle. Written symbols (WS) representations are uses of printed words or texts to explain Archimedes' principle. Formula (F) representations cover the equation of Archimedes' principle, $F = V\rho g$ where F is the buoyant force, V is the volume of liquid displaced, ρ is the density of a liquid, and g is the gravitational acceleration, and the formulae that derived from the main formula. Manipulative (M) representations are uses of tangible objects that can show situations that apply Archimedes' principle like uses of a beaker, a load, a Eureka can, and a spring balance to investigate the phenomenon of buoyancy. Real-life situation (RLS) representations cover uses of Archimedes' principle in real-world settings like submarines, ships, and hot-air balloons. Pictorial (P) representations cover diagrams, sketches, or drawings that can illustrate the ideas and uses of Archimedes' principle. Table (T) representations are the ways to show a relationship of two or more variables in a table. Graph (G) representations are the ways to illustrate a relationship of two or more variables in x- and y-axis.

Lab work consists of activities that require manipulating lab equipment like a Eureka tin, a beaker, a spring balance, loads, and liquids to conduct investigations of Archimedes' principle.

Questioning consists of activities during which a teacher and students exchange questions and answers. The exchanges are called dialogues.

Lectures are activities during which the teacher transmits knowledge to students orally.

Group work and discussion are student-based activities during which they exchange ideas and work with each other to solve specific tasks given by a teacher.

Inquiry is “teaching science as inquiry involves engaging students in using critical thinking skills, which includes: (1) asking questions, (2) designing and carrying out investigations (3) interpreting data as evidence, (4) creating arguments, (5) building models, and (6) communicating findings in the pursuit of deepening their understanding by using logic and evidence about the natural world” (Crawford, 2014, pp. 515).

Contextual knowledge (CxK) covers the teachers' (1) external knowledge of national and school factors and (2) personal knowledge of teaching practices. Contextual knowledge serves as amplifiers and/or filters of the teachers' teaching practices.

Amplifiers are particular parts of the teachers' contextual knowledge (external and personal) that are used to select and emphasize certain aspects of

their subject matter and pedagogical knowledge over others (adapted from Gess-Newsome (2015)).

Filters are particular aspects of the teachers' contextual knowledge (external and personal) that are used to de-emphasize or abandon the use of certain aspects of their subject matter and pedagogical knowledge (adapted from Gess-Newsome (2015)).

Chapter II: Literature Review

Overview

This study was designed to investigate Malaysian physics teachers' teaching practices using ideas and methods from research on pedagogical content knowledge (PCK). The research questions of this study were:

- (1) How do physics teachers teach Archimedes' principle in real classroom settings?
- (2) Why do physics teachers teach it in the ways they do?

The basic problem addressed in this study is that PCK scholars need to know how and why science teachers teach as they do in highly centralized educational systems like Malaysia's. The system is highly centralized in that the curriculum and assessment are standardized, and the Ministry of Education recommends particular teaching practices. The use of a standardized curriculum, assessment, and suggested teaching practices attracted the researcher to study PCK in practice because these contextual factors could influence teachers' PCK in practice. As mentioned earlier, inclusion of contextual knowledge is not common in most PCK models. Hence, examining science teachers' PCK in specific teaching contexts could contribute to the literature on science teacher knowledge and practice.

The Practices of Physics Teachers Using Standardized Curriculum and Assessment

The most common form of centralized educational standardization occurs when a national government specifies the curriculum and the assessments. General suggestions about teaching methods and activities are often included in an official curriculum that the government provides to teachers. As stated by Kerckhoff (2001), standardization is greater when the federal government of a country regulates standards of curricula, learning, and assessment. Schools and teachers are expected to use a common national curriculum and all students need to achieve the same academic standards.

The influence of some facets of centralized standardized systems on teaching practices has been studied. Stevenson and Baker (1991) examined the relationship between a standardized mathematics curriculum and content of instruction in 15 educational systems. They found that in a country with a standardized curriculum, teachers had less variation in the amount of content of they taught, and that more teachers teach more of the standardized curriculum compared to the case of a country with no official national curriculum. They also uncovered that teachers in a standardized education system were more likely to teach the same curriculum and completed more of the curriculum. Additionally, the mathematics content for teaching was not well connected to students' and teachers' individual characteristics when a curriculum was standardized. Stevenson and Baker (1991) mainly emphasized curriculum issues.

Meanwhile, Au (2007) conducted a meta-synthesis study regarding the effects of standardized testing on curriculum and teaching. Au reviewed 49 qualitative studies in the context of the United States educational settings and found three types of controls of standardized testing on curriculum and teaching: (1) content control, (2) formal control, and pedagogic control. Numerous studies that Au reviewed indicated that many teachers taught their students according to the specifics of their standardized test formats, and the alignment between assessment and curriculum was evident. Furthermore, teachers tended to use teacher-centered pedagogies such as lectures to prepare students for standardized tests. Au concluded that standardized tests had major effects on curriculum and teaching controls. However, Au acknowledged that few studies have indicated teachers' increased use of student-centered pedagogies and expansion of content of teaching. A review by Rubin and Kazanjian (2011) provided a similar primary finding. In addition, Crawford (2014) suggested that excessive standardized testing is a barrier to using inquiry and the risk of using inquiry could be too high compared to its benefits.

Au's (2007) review indicated that standardized testing plays a considerable role in shaping teachers' content and pedagogies. The review implied that any changes in the format and requirement of standardized tests would create changes in teachers' teaching practices. Top-down control on schools that creates political pressure on teachers to ensure that their students receive good scores in standardized tests. Au's review was relevant with this

study because standardized tests also apply in Malaysia, the location of this study. With the Ministry of Education's absolute control over the national standardized examination, teachers need to prepare students for the national exam because it is a high-stakes exam that determines students' educational and career paths after high school. Scholars might argue that teaching should not be done for the sake of taking an examination but scholars should realize that teachers might have no choice but to teach students to pass exams because, in the end, teachers are accountable for their students' academic performance.

The studies discussed here are informative but are limited in scope since they have examined only the effects of standardized curriculum on what teachers teach (Stevenson & Baker, 1991). In addition, Au's comprehensive study only reviewed studies about the effects of standardized testing in the United States. Au also did not deeply review teachers' specific teaching activities and use of representations in relation to the standardized testing requirements. The study described here is more comprehensive in that it provides a more complete range of teachers' teaching practices and their reasons for those practices with the idea of pedagogical content knowledge (PCK) as the fundamental guide.

Conceptions of PCK

In 1986, Shulman established the basic idea of pedagogical content knowledge (PCK) as the transformation of subject matter to teaching through multiple strategies. He defined PCK as "...for the most regularly taught topics in one subject's area, the most useful forms of representations of those ideas, the

most powerful analogies, illustrations, examples, explanations, and demonstrations” (Shulman, 1986, pp. 9). He argued that PCK is the central feature in educational contexts that makes teachers professionals through their unique ability to teach subject matter in such a way that learners will understand the content of learning more readily. The birth of PCK as a concept in 1986 indicated the start of a new era that prompted and allowed for a new more comprehensive way of thinking about and observing science teachers’ capability to teach students difficult subject matter and make that subject matter comprehensible to students. Over time, the basic idea of PCK has been extended and modified. The extensions and modifications have been informative but at the same time, the ideas have become more complex and a consistent view of what PCK means has become elusive. As a result, here are several issues associated with the idea.

Since its inception in 1986, scholars have defined PCK in numerous ways. From time to time, they have expanded Shulman’s original definition. Table 1 shows how different scholars defined PCK in multiple ways.

Table 1

Numerous Conceptions of PCK

Studies	Subject Matter	Instructional Strategies and Representations	Student Conceptions	Knowledge of		Context	Purpose of Teaching a Subject Matter	Assessment
				Pedagogy	Curriculum and Media			
Shulman (1986)	D	PCK	PCK	D	D	D	D	
Tamir (1988)	D	PCK	PCK	D	PCK			PCK
Grossman (1990)	D	PCK	PCK	D	PCK	D	PCK	
Marks (1990)	PCK	PCK	PCK		PCK			
Cochran et al. (1993)	PCK		PCK	PCK		PCK		
Fernandez-Balboa & Stiehl (1995)	PCK	PCK	PCK			PCK	PCK	
Magnusson et al. (1999)	D	PCK	PCK	D	PCK	D	PCK	PCK
Carlsen (1999)	D	PCK	PCK	D	PCK	D	PCK	
Hashweh (2005)	PCK	PCK	PCK	PCK	PCK	PCK	PCK	PCK
Loughran et al. (2006)	PCK	PCK	PCK	PCK		PCK	PCK	

Note. PCK: pedagogical content knowledge, D: a distinct knowledge base for teaching.

(Expanded from Van Driel, Verloop, & Vos, 1998)

PCK scholars have different ideas regarding what types of knowledge form PCK. However, as can be seen on the table, many of them accepted Shulman's original definition of PCK (Van Driel et al., 1998; Lee & Luft, 2008).

Realizing that no universal conception of PCK is available, it is up to a researcher to conceptualize his or her study based on the components of PCK that he or she deemed appropriate and relevant to a particular setting and research questions. This way of conceptualizing PCK was evident in the literature where some researchers studied science teachers' PCK using their own conceptions (Van Driel, Berry, & Meirink, 2014). For instance, Loughran, Mulhall, and Berry (2004) developed content representations (CoRes) and pedagogical and professional-experience repertoire (PaP-eRs) while Padilla, Ponce-de-Leon, Rembado, and Garritz (2008) used a conceptual profile model combined with CoRes to portray PCK of four university professors. The use of this way of conceptualizing PCK had fruitfully described the complexity of a teacher's PCK and portrayed the common features of teachers' PCK in teaching a particular topic (Van Driel et al., 2014).

The study presented here was done to examine the following factors as the ones most relevant to understanding the observed teaching practices and reasons for those practices given the setting: subject matter knowledge, pedagogical knowledge, and contextual knowledge. Representations and instructional strategies were embedded in pedagogical knowledge, and curriculum and media

and assessment knowledge were embedded in contextual knowledge. While it is somewhat unusual to place curriculum and media and assessment in the context factor, this seemed reasonable for this study given that curriculum and media and assessment are prescribed by the federal government in a centralized system like Malaysia's. Particular attention was given to contextual knowledge because it was considered especially important to understand the specific context and, as shown in Table 1, it was not considered as often in the various PCK models and was rather uncommon in many PCK models (Kind, 2015). In terms of the construct of "purpose of teaching a subject matter" or orientation to teaching science or teacher beliefs, it is now under amplifiers and filters in the consensus PCK model (Gess-Newsome, 2015). Amplifiers and filters could cover contexts, personal knowledge, and beliefs (Gess-Newsome, 2015). The researcher put them in the construct of contextual knowledge that covered external and personal factors of teaching.

Issues in PCK

In what contexts has PCK been studied? Shulman (2015) recognized that his original PCK conception was "insufficiently attentive to questions of the broader social and cultural context" (pp. 10). He realized that contexts are powerful factors that can influence teaching and learning. Shulman urged researchers to look at how different contexts could inform different forms of PCK because he believed that teaching and learning are shaped by particular settings.

Up to this time, many scholars around the globe have adopted the idea of PCK. Nonetheless, the major PCK studies so far had been conducted mainly in developed nations, especially in the United States, Australia, the Netherlands, and the United Kingdom. PCK originated from the context of the United States because the founder of this notion (Shulman) is an American scholar. Furthermore, many leading scholars of PCK are from developed countries (Van Driel, Gess-Newsome, Roehrig, Luft, Loughran, Berry, Grossman, Magnusson, Krajcik, Tamir, Kind, etc.). Just a few of them are from developing countries (like Rollnick and colleagues who are in South Africa, Halai in Pakistan, Usak in Turkey, and Padilla in Mexico). Both the conceptualization and the operationalization of PCK in research were expected to be influenced by contexts of a particular country. Adopting what were originally developed nations' PCK factors to ones of developing nations' requires consideration of possible effects of the context of the national education system in a specific country.

Is PCK knowledge or practice or both? Shulman (2015) recognized that his original PCK conception gave primary attention to teachers' knowledge and too little to teachers' actual practices. The importance of emphasizing studies of practice was supported by Henze and Van Driel (2015) and Settlage (2013). Henze and Van Driel argued that PCK researchers should make direct observation of classroom teaching to get insight on how teachers actually teach. They further argued that researchers should also investigate teachers' reasons for using particular teaching practices. Henze and Van Driel (2015) also argue that there is

a difference between “knowing” and “doing” PCK, which implies that translation of knowledge of teaching to real teaching is not necessarily straightforward.

Teachers may face problems in transforming their knowledge into action. This is called the “problem of enactment” (Kennedy, 1999).

Seeking resolution to the issue of whether PCK is what teachers know or what teachers do is not productive. This is not an either-or question. Instead, researchers should see PCK as knowledge used in practice. Capturing PCK in practice means understanding practices of teaching science from PCK perspectives that might reveal personal and contextual reasons for using particular teaching activities and representations when teaching a particular topic to a particular group of students.

What are the sources of PCK? Researchers interested in PCK have considered several sources of PCK. They proposed personal and canonical PCK (Smith & Banilower, 2015; Park & Suh, 2015). Smith and Banilower (2015) stated that personal PCK forms through personal teaching experience, while canonical PCK forms via consensus among many teachers on shared practices, and that both types of PCK may exist. Park and Suh (2015) used the terms “idiosyncratic PCK” and “indispensable PCK” instead of “personal PCK” and “canonical PCK” to describe a similar dichotomy.

Park and Suh (2015) also suggested that the two primary sources of canonical PCK are canonical science and current theories of learning. They argue that scientific ideas and facts are universally accepted, while teachers and

educators learn many common learning theories like the behaviorist and constructivist theories.

For this study, the researcher argues that a broader view of the sources of canonical PCK than the ones given above is needed. As Shulman (2015) suggested, PCK scholars should look at how contexts shape teachers' PCK in practice. Thus, consideration of contextual factors was needed. In this study, special attention was given to the effects of the national education system used by Malaysia because it could influence teachers' PCK in practice. The standardized national curriculum and national examination of a country like Malaysia could influence teaching practices of teachers and reasons for using those practices. In fact, these factors were considered canonical because they were developed and sanctioned by the Ministry of Education.

Conceptual Framework

Several models of teacher knowledge inform what is meant by PCK. The most current model is the general model of teacher professional knowledge and skill including PCK (Gess-Newsome, 2015). The model is too broad and inclusive with respect to the purposes of this study. Two earlier models were more suited for consideration regarding this study. Those models are integrative and transformative models as proposed by Gess-Newsome (1999) and they are more specific to PCK. This study adopted the integrative model. Figure 1 shows the model.

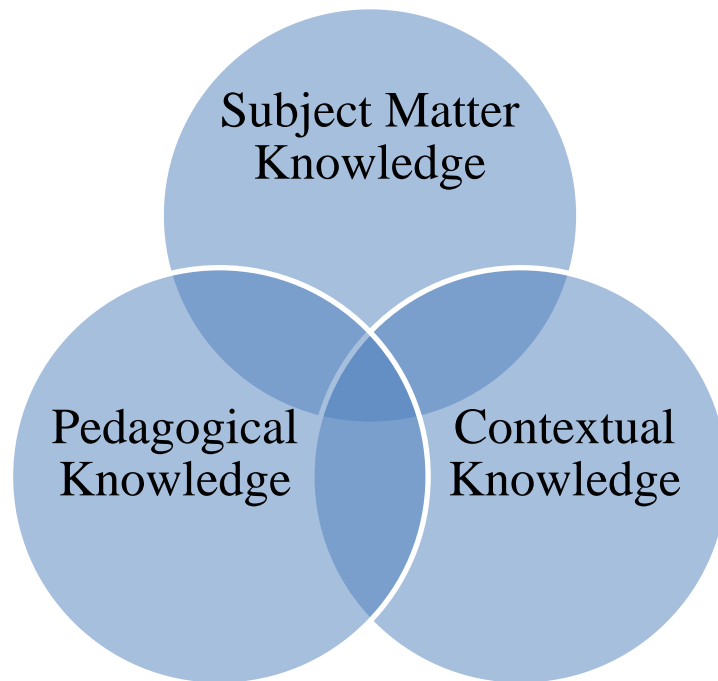


Figure 1. The integrative PCK model.

(Modified from Gess-Newsome, 1999, pp. 12 and was ordered from the
Copyright Clearance Center)

The integrative model specifies three knowledge bases: subject matter, pedagogy, and context, and shows the possible interactions among the three domains. The integrative model describes how the three domains are developed separately, but integrated when a teacher is teaching (Gess-Newsome, 1999). This model was chosen because many teacher education programs in Malaysia implement an integrative kind of teacher knowledge model. This basic model was also chosen because it includes subject matter, pedagogy, and context separately along with possible interactions among those three types of knowledge bases in practice.

Subject matter knowledge. This study defined knowledge of subject matter as knowledge regarding “facts, concepts, principles, and procedures that are typically taught in secondary school classrooms” (Gess-Newsome, 1999, p. 55) or could be named *subject matter for teaching* (Settlage, 2013; Van Dijk & Kattman, 2007). Specifically, this study looked at subject matter knowledge in practice: how physics teachers used their knowledge of Archimedes’ principle for teaching students ideas about buoyancy. Particular attention was given to the teachers’ decisions about what to teach and how to organize what they taught given the national curriculum (Ministry of Education, 2005).

Hewitt (2002) defined Archimedes’ principle as “an immersed body is buoyed up by a force equal to the weight of the fluid it displaces” (pp. 251). When explaining the principle, he first explained the existence of a buoyant force and the apparent loss of weight experienced by an object immersed in a liquid. He then explained the main concept of Archimedes’ principle regarding the weight of liquid displaced and the buoyant force. Finally, he explained the concepts of flotation and submersion. The Ministry of Education requires that teachers teach four ideas of Archimedes’ principle: (1) the loss of weight of an object in a liquid, (2) the weight of liquid displaced, (3) flotation, and (4) submersion. These requirements fit with the ideas that Hewitt (2002) used to explain Archimedes’ principle.

Pedagogical knowledge. This study defined pedagogical knowledge as knowledge of teaching activities and representations. Pedagogical knowledge

included knowledge of subject-specific strategies (physics) and knowledge of topic-specific strategies (Archimedes' principle ideas) (Hashweh, 2005; Magnusson et al., 1999). The Ministry required teaching four ideas that make up Archimedes' principle: (1) the loss of weight of an object in a liquid, (2) the weight of liquid displaced, (3) flotation, and (4) submersion.

Special attention was given to teachers' pedagogical knowledge in practice given that the Ministry of Education (2005) suggests three primary teaching activities for teaching Archimedes' principle – lab work, discussion, and physical models. However, the teachers' use of other activities was also expected. Treagust and Tsui (2014) found that many science teachers use other activities such as lectures, questioning, and demonstrations for teaching science as well. They discovered that teachers use questioning activities to identify students' current conception of a particular idea, while lectures are used to teach students to use the right keywords for explaining a particular idea of science.

Representations of ideas were also included in pedagogical knowledge. Lesh translation model (Lesh & Doerr, 2003) was used to frame teachers' multiple representations that they used in practice. The model covers eight modes of representations: (1) verbal symbols (VS), (2) written symbols (WS), (3) pictures (P), (4) real-life situations (RLS), (5) formulae (F), (6) manipulatives (M), (7) tables, and (8) graphs. The model also covers translations of representations across and within the modes. A complete translation of representations covers translations of all types of modes, across and within.

The Lesh translation model is commonly used in mathematics (Cramer, 2003). However, its applicability for science subjects and topics is possible because the modes of representations could be generic for science subjects and topics. A physics topic like Archimedes' principle also has several equations that could serve as formulae (F) representations. The physics topic is also used in real-world applications like submarines that could serve as real-life situation (RLS) representations. Other modes of representations are highly possible for Archimedes' principle, except for tables (T) and graphs (G) that might not be applicable.

This study aimed to investigate the translations of representations of the ideas of Archimedes' principle, in a specific order, to determine the steps of translating from one mode to another. In doing so, the key modes were expected to emerge and the researcher could suggest the required modes for teaching Archimedes' principle.

Contextual knowledge. Knowledge of contexts includes teachers' knowledge of external and internal or personal factors. External knowledge is a broad category and includes factors such as the national curriculum and assessment and school-based resources. Personal knowledge may also be part of individual teachers' teaching experiences such as usefulness of certain teaching activities in teaching Archimedes' principle.

External and personal factors could be classified as either "amplifiers" or "filters" of teaching. These terms come from the most recent model of teacher

knowledge and practice (Gess-Newsome, 2015). Amplifiers and filters may refer to teachers' personal knowledge, contexts of teaching, or beliefs (Gess-Newsome, 2015). Amplifiers and filters could be external or personal depending on how teachers perceive them as being informed by the system or situation (external) or their own decisions in teaching (personal). However, there could be interactions between them.

Nonetheless, the ways in which amplifiers and filters are currently defined are not clear in part because they are very new and not well established terms. Their use started in 2015 after a group of scholars created a consensus model of PCK (Gess-Newsome, 2015). Although the terms are inclusive, they are vague in nature because they could include too many factors: external and internal or personal. In addition, a factor may play dual roles as an amplifier and a filter. For instance, a national curriculum could play the role as an amplifier because all teachers need to use the standardized curriculum, as is the case in Malaysia. At the same time, the national curriculum could be a filter because it predetermines subject matter that teachers should teach and thus eliminates or at least limits other possibilities. This made the conception of amplifiers and filters difficult for this study. The researcher attempted to refine the terms by using them as part of the contextual knowledge domain.

Studies of PCK in Practice

Rollnick (2016) studied seven experienced high school science teachers' subject matter knowledge and pedagogical content knowledge in South Africa.

The study had to do with the development of PCK. The topic of interest was semiconductors. Even though teachers were experienced, they were beginners in terms of teaching semiconductors because the topic had been recently introduced in the national curriculum. Rollnick used video recordings of teachers' live instruction, lesson plans, interviews, teachers' journal, audio recordings of peer teaching, project reports, and concept maps. She also used Content Representations (CoRes) and Pedagogical and Professional-experience Repertoires (PaP-eRs) (Loughran et al., 2004) to portray and capture teachers' PCK. Three main ideas of semiconductors were investigated. Key episodes of teaching were identified and coded from video recordings. Rollnick (2016) found that science teachers' subject matter knowledge and pedagogical knowledge were developed hand-in-hand. Nonetheless, the study described here differs from the Rollnick study in that her study was about "PCK development" and not "PCK as it is."

Park and Oliver (2008) conducted a study on PCK in teaching practices of three experienced chemistry teachers. They proposed five components of PCK (orientation to teaching, student knowledge, curriculum knowledge, knowledge of instructional strategies and representations, and assessment knowledge) as the initial conceptual framework and working definition of PCK. A multiple case study design was used, and they utilized numerous data sources: classroom observations, semi-structured interviews, lesson plans, teachers' written reflections, students' work samples and researchers' field notes. Data were

analyzed using the constant comparative method, enumerative approach, and in-depth analysis of explicit PCK. The explicit PCK was captured using three guides: what the teacher did, why the teacher did as the teacher did, and what the teacher knew. Park and Oliver used the observation data as the primary source to identify explicit PCK, but other data sources (interviews, written reflections, etc.) enriched the descriptions of the explicit PCK. The researchers found that each of the three teachers had idiosyncratic PCK or personal PCK even though they planned the same unit together and taught at the same school. Idiosyncratic PCK was formed through teachers' personal orientation to teaching, students' characteristics, teaching experience, and personal characteristics. However, the teachers also had common characteristics of PCK. Oliver and Park's study informed that personal and canonical PCK exist. Nevertheless, the factor of national context was not evident because this factor was not explicit in the context of their study.

Halai (2012) made a review of twenty (20) action research studies regarding innovative strategies of teaching practices. The study was located in Pakistan. She used a qualitative meta-synthesis to analyze the dissertations. She found that innovative practices of teaching did not fit with the practice of assessment implemented in Pakistan due to a standardized testing. Halai's study informed the researcher that assessment is a significant context of teaching that should be taken into count to understand science teachers' PCK in practice. That was why this study considered assessment, especially the national assessment (a

standardized exam), as the central factor in shaping teachers' practices of teaching. However, the national assessment served as the contextual knowledge of this study, and was not studied as the assessment knowledge was.

Halai's studies suggested the possible effect of contextual factors like the national status, assessment practices, and school contexts to PCK in practice. Meanwhile, Park and Oliver's study informed the researcher that personal and canonical PCK occur. Personal PCK formed through a teacher's action during teaching even though the teachers in Park and Oliver's study worked together to plan the curriculum unit for teaching. In addition, Rollnick's and Park et al.'s studies used multiple data sources to capture PCK in practice. This study adopted the similar methods of collecting data: classroom observations, interviews, and collection of documents. The use of various data sources could provide complete pictures of teachers' PCK in practice.

Settlage (2013) wrote an essay regarding shortcomings of PCK. He argued that many PCK studies did not connect knowledge of teaching with classroom teaching practices and contexts. He added that PCK researchers in science had put a greater emphasis on the knowledge part of PCK because teachers' knowledge is relatively easier to capture through methods such as a conceptual inventory. Settlage's essay informed the researcher that a study on PCK in practice should be conducted to see how teachers' practice of teaching connected to their knowledge about their teaching.

Furthermore, a major and current review of PCK studies was made by Van Driel, Berry, and Meirink (2014). This review helped this study to identify gaps in PCK research that this study can begin to fill. They reviewed 119 articles regarding PCK studies from January 2005 to November 2012 and covered studies on inservice and preservice science teachers. Van Driel et al. included empirical studies, literature reviews, position papers, and articles about the testing and development of instruments and procedures. In terms of “PCK as it is,” Van Driel and colleagues found that this research line is still in its early stages. Therefore, it was valuable to conduct a study on PCK “as it is” to contribute to the literature.

Overall, this study was formulated to develop our understanding of PCK in practice “as it is.” To this end, the study provided descriptions of how and why in-service physics teachers teach as they do a specific topic, Archimedes’ principle. Furthermore, this study considered not only subject matter knowledge, pedagogical knowledge, and contextual knowledge separately, but also the integrations among them in practice.

Studies on Archimedes’ Principle

Mohd Salleh and Abdullah (2008) studied Malaysian physics teachers’ perceptions on teaching Archimedes’ principle. Nine physics teachers were interviewed. Researchers found that all teachers agreed that Archimedes’ principle is a hard topic to teach and they allocated more time to teaching it than they expected to. Loverude, Kautz, and Heron (2003) had discovered a similar finding; Archimedes’ principle was a challenging topic to understand. This

finding was also applicable for a study conducted by She (2002). Overall, the literature had suggested the topic of Archimedes' principle was difficult to teach for students. Hence, the topic was chosen.

A follow-up study conducted by Loverude and colleagues (Heron, Loverude, Shaffer, & McDermott, 2003) indicated that teaching students about flotation and submersion would be effective if instructors used a set of objects of different mass, but with the same volume, and asked students to predict the amount of liquid displaced in each object. They also found that students' success in understanding Archimedes' principle would not solely depend on the use of lab-based activities and tutorials, but on the details of those activities. Hands-on experience was not a guarantee that students would clearly comprehend Archimedes' principle. The researchers found that it was important to take into account students' initial conception of flotation and submersion because the participants found it difficult to make accurate predictions of those phenomena. Flotation and submersion seemed to be advanced concepts because students needed to apply fundamental concepts such as density, mass, and volume before learning the two concepts. In fact, Heron and colleagues found that some students needed to be taught about the fundamental concepts because they could not apply the basic concepts easily. Heron et al.'s study implied that teaching Archimedes' principle required detailed instruction where students should be given opportunities to conduct lab-based inquiry and discussion in meaningful ways. The detailed instruction would require students to actively participate in the

learning process and reconstruct their initial understandings of Archimedes' principle.

Studies on Science Teaching Activities

Scholars (Hofstein & Kind, 2012; Duit et al., 2014) support the use of inquiry-based learning for teaching science. Teaching science as inquiry is defined as “engaging students in using critical thinking skills, which includes asking questions, designing and carrying out investigations, interpreting data as evidence, creating arguments, building models, and communicating findings in the pursuit of deepening their understanding by using logic and evidence about the natural world” (Crawford, 2014, p. 525). This definition clarifies that inquiry is not just about doing laboratory work, but also engaging students in discussion. Ministry of Education (2005) also specifically recommends that teachers use laboratory work and discussion for teaching Archimedes' principle. Additionally, the ministry also wants teachers to use models. Scholars (Coll & Lajium, 2011) mentioned that modeling could help students to visualize scientific phenomena and thereby learn the concepts connected to the phenomena.

Crawford (2014) conducted a review of research on inquiry-based learning. She found that inquiry is the prominent way people learn science through scientific investigations and it is commonly used to create interest among young learners in science fields. The adoption of inquiry, hence, could help students learn Archimedes' principle in exciting manners by carefully conducting laboratory work to investigate the relationship between variables, and actively

debate their findings using evidence. In addition, teachers could assign students to make physical models demonstrating flotation and immersion like Cartesian divers or submarines using low-cost materials like bottles and straws. These ways of teaching and learning of Archimedes' principle could make ideas of the principle more accessible and comprehensible to students, thus achieving the meaning of PCK in its fullest sense – using multiple strategies and representations of ideas to make subject matter understandable to learners.

However, not all physics teachers use inquiry. Duit, Schecker, Hottecke, and Niedderer (2014) did a review of research on physics instructional practices. They found that many physics teachers adopted the view of teaching as “transmissive” rather than “constructive” and primarily utilized teacher-centered approaches. They recommended physics education researchers study regular teaching practices of physics teachers to understand factors that may impede adoption of a constructive view of learning, which implies use of the inquiry method.

Thomas and Watters (2015) also came to the same conclusions as Duit et al. (2014). Through a review of studies, Thomas and Watters found that many Malaysian science teachers use a didactic type of teaching and a whole-class approach of instruction. Consequential factors identified were large class sizes and poor learning facilities. Phang, Abu, Bilal Ali, and Saleh (2014) obtained the same result through their study. Phang et al. discovered that many science teachers taught using teacher-centered approaches, mostly teaching for preparing

students for exams, and did not always conduct lab work with students. Saleh and Yakob (2014) also found the same result regarding the adoption of a didactic approach to teaching.

However, other studies indicate another perspective. Luan, Atan, and Sabudin (2010) did a study of 209 science teachers in Malaysia on their perception of adopting inquiry-based learning. Science teachers were found to have moderate intentions to adopt inquiry more than didactic teaching. Luan et al. (2010) also found that many teachers thought that they needed to guide students in conducting inquiry activities. Luan et al.'s study informed that science teachers intended to utilize inquiry, and these teachers were inclined to guide students instead of using open-ended inquiry.

Hofstein and Kind (2012) and Duit et al. (2014) also realized that not all teachers use open-ended inquiry. Many of them use “cookbook” approaches whereby they strictly guide students on how to conduct an inquiry. Besides, inquiry activities in these cases consist of merely manipulating objects and materials, and students do not engage much in active discussions.

Besides inquiry, scholars also found that other teaching activities are useful for teaching science. Treagust and Tsui (2014) conducted a review of general teaching activities for teaching science. They found that many science teachers use six types of teaching activities: (1) demos, (2) lectures, (3) IRF (Initiation-Response-Feedback) questioning, (4) scientific reasoning, (5) representational learning, and (6) twenty-first-century science teaching (Lemke,

1990; Coll & Lajium, 2011; Geelan, 2012; Hofstein & Lunetta, 2004; Simon, Erduran, & Osborne, 2006). The first three are more teacher-centered while the rest are more student-centered. Scientific reasoning, representational learning, and twenty-first-century teaching are consistent with inquiry methods, while the other three are not. However, Treagust and Tsui thought that those three activities – demos, lectures, and questioning – are still useful for teaching science. Demos can show students dramatic effects of a phenomenon while lectures can teach students to use correct scientific words in explaining a phenomenon. In addition, questioning can allow teachers to identify students' current ideas in a particular idea.

It is up to physics teachers to decide which activities to use for teaching Archimedes' principle. Even though inquiry is the recommended method (Ministry of Education, 2005, Hofstein & Kind 2012, Duit et al., 2014), teachers may have personal reasons for using other teaching activities. This study was interested in determining teachers' reasons for using particular teaching activities when teaching Archimedes' principle. This effort was important to illuminate barriers, both personal and contextual, to adoption of the recommended teaching activities of teaching Archimedes' principle – lab work, discussions, and models as suggested by the Ministry. From this basis of understanding, action can be taken to fix the problems.

Studies on Representations

When Shulman (1986) first defined PCK, he used the word “representation” in linking subject matter knowledge with pedagogical knowledge. Examining science teachers’ representations in practice is central to understand the ways they portrayed Archimedes’ principle with appropriate representations. This study reviewed several studies about multiple external representations (MERs) as the basis to understand the use of Lesh’s translation model, which this study adopted. Studies that used Lesh’s model were also reviewed to demonstrate the main findings that informed this study.

One reason for using multiple representations for teaching instead of a single representation is that several representations are more useful when presenting complex information (de Jong et al., 1998). Other reasons are MERs could be used to enhance students’ in-depth understanding of a concept and capture students’ diverse interests (Ainsworth, 1999). Over the past ten years, the notion of MERs has been used widely in mathematics education and has influenced science pedagogical approaches (Treagust & Tsui, 2014).

Lesh’s translation model is a type of MERs that has been used commonly in mathematics education (Cramer, 2003). However, its foundation was partly built from science education through Bruner’s three representations: enactive, iconic, and symbolic (Bruner, 1961). Lesh’s model (Lesh & Doerr, 2003) expanded the three representations to five more representations: real-life situations, formulae, tables, graphs, and pictures. This study attempted to broaden

the Lesh's model to science education, specifically to understand the translations of representations across and within modes in physics teachers' actual classroom teaching.

Many studies that have used Lesh's model have focused on the topic of fractions (e.g. Chahine, 2011; Pal, 2014) because it is a difficult topic for students, especially for elementary school students. It is also commonly used in problem solving activities of mathematics such as model-eliciting activities (MEAs) (Stohlmann, Moore, & Cramer, 2013). Lesh's model could also be used as a guide in planning teaching activities to meet students' needs (Cramer, 2003).

Chahine (2011) studied the effects of using representation-based interventions on fifth-grade students when solving problems related to fractions using a quasi-experimental design. Eighteen students were randomly grouped into experimental and control groups. The results showed that students from the experimental group who went through research-based instruction (RBI) outperformed the traditional-based instruction (TBI) student group. The RBI student group also showed more translation across and within modes of representations than the TBI student group. Chahine (2011) noted that in a traditional teaching method where teachers and textbooks are the decisive authority, students are taught using rote learning approaches and simple recall of facts. The intervention on the RBI student group indicated that the use of multiple representations and their translations could help teachers shift to reformed instruction. The pedagogical implication is that teachers need to be encouraged to

use research-based pedagogies that could create meaningful learning for students. Chahine further argued that without reformed-based pedagogies, the traditional teaching approach would persist in mathematics subjects, especially in Lebanon where the study was conducted.

Pal (2014) also conducted a study regarding MERs. The research design was a quasi-experimental design, which was similar to Chahine (2011) where students were randomly assigned into experimental (MERs) and control (conventional) groups. The findings were also similar to Chahine (2011) where the experimental group had higher scores than the control group. In addition, the experimental group used manipulative representations more meaningfully when given fraction problems. The students from the experimental group were excited to learn fractions and thought that using fraction kits, circles, and sharing pizza and cookies made learning fun and easy to solve the fraction problems. This result demonstrated the crucial role of manipulative representations to show students how fractions are applied through the use of tangible objects.

Chahine's and Pal's studies reveal the usefulness of utilizing multiple representations in teaching a difficult topic (fractions) in which students who learned through MERs had better scores than their counterparts. Furthermore, Pal's study suggests the central role of manipulative representations in showing students how fractions work.

In the context of this study, Archimedes' principle is also a difficult topic for students to understand (Mohd Salleh & Abdullah, 2008). Complexity in

teaching Archimedes' principle may require the adoption of MERs where teachers need to translate one representation to another across and within the modes.

Moreover, teachers may need to consider the use of tangible objects to teach students about flotation and submersion ideas as recommended by the national curriculum (Ministry of Education, 2005).

More importantly, teachers need to ensure that the translation across and within modes of representations to take into account student-generated representations because it could help teachers capture students' current understanding. Domination of teacher-generated representations would imply that teachers are only adopting a traditional teaching approach, and it was not the intention of the national curriculum for teachers to use a conventional approach. Thus, there is a need to examine the use of multiple representations in teaching practice "as it is" to determine if teachers' practices are consistent with the national curriculum's aim.

Studies on Amplifiers and Filters

To date, few studies have used the terms amplifiers and filters because the terms are very new. Rollnick (2016) recognized several filters at the school level such as lack of resources and student factors such as English proficiency. Rollnick acknowledged that amplifiers and filters, especially in the context of teaching, could moderate characteristics of teachers' PCK in practice. In her study, some teachers taught in schools with better resources than others, and the teachers adopted certain pedagogical strategies according to their specific contexts. The

English language proficiency factor was also evident for some teachers' cases but not for others. Thus, Rollnick's study indicated that filters play a role in moderating teachers' PCK in practice.

Previous studies on PCK have used terms such as "contextual barriers" that could be synonymous with "contextual filters." For instance, Fernandez-Balboa and Stiehl (1995) investigated PCK of college professors and found several contextual barriers of professors' teaching: large class sizes, time limitations, and insufficient appropriate resources. They found that these barriers made teaching in the university difficult, but the professors tried to overcome the barriers using strategies such as borrowing curricular materials from other departments and public schools. This finding suggests that when teachers face constraints, they could employ other alternatives to overcome the problems. This action is important to ensure that contextual barriers are not an overwhelming problem for teaching.

It was important to continue studying amplifiers and filters that could shape teachers' PCK in practice because actual teaching practice in classrooms could be influenced by many factors. This study continues the research on amplifiers and filters to show the significance for teachers in a centralized education system in a developing nation. However, one challenge was to differentiate amplifiers and filters. Although the literature (Gess-Newsome, 2015) has suggested some examples, they are not yet clear enough because the terms are

relatively new in the PCK literature. Thus, evidence from the current study attempts to differentiate these terms.

Qualitative Research: Case Study Design

There are many options regarding the use of qualitative in-depth study design. Creswell (2013) proposed five main approaches: (1) narrative research (2) phenomenological research (3) grounded theory research (4) ethnographic research and (5) case study research. However, this study decided to use the case study design because it fits with the primary goal of using case study – developing an in-depth description and analysis of multiple cases (Creswell, 2013) covering physics teachers' teaching activities, representations, and reasons for using them in order to teach Archimedes' principle. Other designs like narrative research were not relevant because this study did not aim to investigate the lives of individual teachers, plus this study did not intend to build a theory from those cases involving a grounded theory design. Hence, the use of case study design was particularly appropriate and useful, especially by using multiple data sources like observations, interviews, and documents (Creswell, 2013).

Yazan (2015) made a review of three types of case studies that established by three scholars, Yin (2014), Merriam (1998), and Stake (1995). A comparison was made, and Yazan found significant differences among those three scholars regarding how to define a case study, epistemological commitments, and how to design a case study, gather data, analyze data, and validate data. Yazan concluded that if a researcher adopts a constructivist paradigm, depending heavily on

literature review that informs a design, and if the researcher wants to get holistic descriptions and analysis, use only qualitative data sources like observations, interviews, and documents, and make triangulation, members checks, and thick descriptions, then Merriam's case study design is particularly relevant. Other designs by Yin and Stake were not explicitly relevant because Yin employs a positivist paradigm while Stake suggested the use of a flexible design that this study did not adopt.

This study employed Merriam's case study design because it fit with many features of the case study that she proposed like adopting a constructivist paradigm, drawing from qualitative data sources, and using literature review as the source for designing research questions (Yazan, 2015). It was clear that this study adopted two research questions espoused by Henze and Van Driel (2015). This study also adopted multiple data sources suggested by Merriam (1998), namely observations, interviews, and collection and analysis of documents. Each data source has strengths and limitations.

Patton (2002) explains that direct observation at the location of research can create a chance for a researcher to learn things that participants might be reluctant to talk about in an interview. For this study, observing physics teachers' classroom teaching and creating recordings of teaching using a voice recorder helped the researcher to capture real action that happened in a classroom. This method and the data source can primarily inform the first research question. However, the researcher recognized that his method of observation was lacking

regarding the influence of interpreting how teachers were teaching. To minimize this bias, the researcher primarily depended on transcriptions of voice records of teaching that can massively give information about what teachers were saying during instructions and conducted a member checking method to verify analysis of data.

For the interview methods, Rubin and Rubin (2012) states that interviews can provide in-depth information and allow exploration of complex issues. This study adopted interviews as one of the research methods for investigating physics teachers' instructional practices. Interviews were the primary data source of the second research question. The interview method fitted with the nature of "why" research questions because it can help the researcher to know in-depth physics teachers' thinking about their classroom teaching and personal and contextual factors that contributed to their practices of teaching Archimedes' principle.

For the collection of documents, this method is useful for supplementing data of observations and interviews (Patton, 2002). In this study, a collection of documents were made – lesson plans, slides of teaching, learning modules, and photos of teachers' and students' work. All of these documents were highly useful for answering research question #1 about how those physics teachers taught Archimedes' principle.

Methodological Aspects of Capturing PCK in Practice

Methodology to use for eliciting PCK in practice has triggered a huge debate among scholars. PCK is complex and tacit in nature (Van Driel et al.,

1998, Loughran et al., 2012). Eliciting PCK in practice, thus, is not an easy or straightforward task. Baxter and Lederman (1999) abridged the notion of PCK as “what a teacher knows, what a teacher does, and the reasons for the teacher’s actions” (p. 158). Relying on just a single instrument to capture PCK in practice is not appropriate because it can mislead as to the portrayal of PCK of science teachers. For instance, depending solely on classroom observation data can limit insight of why teachers teach the ways they do because the kind of data can mainly give information on what teachers do – but not why. Similarly, using interviews as the single source of data makes PCK limited, focusing just on the knowledge part of teaching, and does not provide a complete understanding on how teachers actually teach. Thus, the use of multiple data sources to capture PCK in practice is necessary.

Kind (2009) reviewed methods used to capture PCK in practice and found three main approaches: an *in situ* approach using regular research methods, an *in situ* approach using “rubrics,” and the use of prompts. This study used the first approach.

Researchers who adopted the first approach to elicit PCK in practice (*in situ* data utilizing standard research methods) usually collect data over a substantial period instead of a single class period. For example, De Jong and Van Driel (2004) conducted a study on eight chemistry student teachers’ PCK in a one-year post-graduate teacher education program. Pre- and post-lesson interviews, audio recordings of lessons, and analysis of relevant chapters of

textbooks used by participants were conducted. An investigator triangulation method was also used. In addition, Park and Oliver (2008) conducted a study on PCK of three experienced chemistry teachers. They conducted classroom observations and semi-structured interviews, reviewed lesson plans, solicited written reflections of teachers, looked at students' work samples, and analyzed researchers' field notes. Usually, studies adopting this approach of eliciting PCK are small in scale (Van Driel, Berry, & Meirink, 2014). Thus, generalizability of findings is limited. However, this methodology can provide rich descriptions of teachers' PCK in practice because multiple data sources can be triangulated, thus provide a holistic view on teachers' PCK (Kind, 2009).

The second approach used by some scholars is the use of "rubrics" that are developed from *in situ* data focused on PCK. The uses of rubrics are multiple: the instruments of Content Representation (CoRe) and Pedagogical and Professional-experience Repertoires (PaP-eRs) (Loughran et al., 2006), and a devised scoring rubric (Lee, Brown, Luft, & Roehrig, 2007; Park, Jang, Chen, & Jung, 2011). Loughran et al. (2004, 2006, 2012) created the CoRe to document teachers' knowledge on how to teach big ideas of science and used eight prompts to elicit teachers' plan to teach the big ideas through an empty table given to teachers to fill in. Meanwhile, PaP-eRs is a narrative account used to provide context to particular instances of teaching segments or key episodes. CoRe and PaP-eRs have gained attention from scholars (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008; Bertram & Loughran, 2012) and those tools are useful to articulate,

document, portray, and capture teacher specific professional knowledge (TSPK). CoRe is the manifestation of TSPK, and it forms canonical PCK of science teachers (Gess-Newsome, 2015). However, completing CoRe consumes a significant amount of time for science teachers, and teachers need to be trained to use the tool (Kind, 2009).

Regarding the use of scoring rubrics, Lee et al. (2007) and Park et al. (2011) use *in situ* data from classroom teaching or interviews to develop rubrics. Lee and colleagues (2007) used two PCK components: knowledge of students' conceptions and knowledge of instructional strategies and representations. They used interviews data to refine the two elements of PCK that are most evident and accepted by many scholars. They then proposed three levels of PCK: limited, basic, and proficient. They found that all science teachers in their study had either limited or basic levels of PCK. Meanwhile, Park and colleagues (2011) used *in situ* data from classroom observations and interviews to create rubrics of PCK. The rubric is built based on two PCK components: knowledge of students' conceptions and knowledge of instructional strategies and representations. Park and colleagues used four levels of PCK, from limited (score 1) to exemplary (score 4). The use of rubrics is useful to decide current levels in teachers' PCK development (Van Driel, Berry, & Meirink) and is a good alternative to CoRe (Kind, 2009).

The third approach used by other scholars was the adoption of prompts. Researchers like Kanter and Konstantopoulos (2010) used video segments as

probes to capture nine science teachers' PCK and teachers needed to produce detailed written analysis of videotapes emphasizing key episodes of their teaching. The lessons were about calorimetry and body systems from the curriculum of "I, Bio," Project-based Science. Researchers then gave a score of 1 to 7 for each episode written. The use of prompts is less time consuming compared to CoRe, but the approach has the effect of a "snapshot" in that it may just disclose a few parts of teachers' PCK (Kind, 2009).

The researcher decided to use the first approach and not others because it could provide the most direct information about the teachers' practices and reasons for their practices – their PCK in practice. In addition, the first approach is more feasible because it is less disruptive to teachers and thus more accessible in the Malaysian context. The first approach also saved time for collecting and analyzing data compared to other approaches, especially the content representation (CoRe). Additionally, the researcher did not use rubrics as the method because quantifying three teachers' PCK (three physics teachers in his study) may not be sufficient to provide quantitative insights. Moreover, the third approach, which has the snapshot effect, could create limited pictures of teachers' PCK in practice. Therefore, the first approach was deemed the most useful and practical, considering that this study was not funded by any parties and needed to be completed in a relatively short time.

In relation to the selection of the first approach, Henze and Van Driel (2015) recommended that PCK researchers adopt a qualitative in-depth study

design to investigate how teachers teach in real classroom settings and why they teach as they do. Henze and Van Driel thought that an in-depth qualitative study is central to capture PCK in classroom teaching better. Their suggestion is consistent with the nature of PCK assessment where Baxter and Lederman (1999) found that PCK consisted mainly of qualitative forms.

As mentioned earlier, this study employed Merriam's (1998) case study design because it fit with many features of the case study approach that she proposed like adopting a constructivist paradigm and qualitative data sources (Yazan, 2015). A qualitative case study requires the use of multiple data sources to give holistic descriptions of physics teachers' PCK in practice. In this study, numerous data sources were used: audio recordings of classroom teaching, pre- and post-teaching interviews, and collection of relevant documents. Triangulation of data sources provided complete pictures of teachers' classroom teaching and reasons for using particular teaching methods. Audio recordings of teaching can provide data on how teachers teach main ideas of Archimedes' principle, pre- and post-teaching interviews can give information on why teachers teach Archimedes' principle the ways they do, and documents like slides of teaching, written questions, and student posters were useful to supplement descriptions of classroom teaching, especially for the sake of providing data on teachers' ideas for teaching Archimedes' principle.

Chapter III: Research Methods

Research Paradigm

The researcher employed an interpretive research paradigm (Merriam, 1998) where realities (i.e., physics teachers' classroom practices and reasons for adopting those practices) were subjective and complex. The teachers had their own preference of teaching physics and buoyancy, they knew what they were doing, and had reasons for practicing goals and teaching activities that they deemed useful or suitable. Their voices and views about their teaching should be perceived as unique, and be treated fairly by the researcher. Thus, the researcher was committed to using data from the teachers' classroom practices and reasons for adopting those practices to understand the complex interplay of the teachers' subject matter knowledge on Archimedes' principle, teaching activities and representations, and contextual factors (e.g., the national curriculum, national assessment, school contexts) that might inform their classroom practices.

Contexts

National context. Malaysia has had a centralized education system since its Independence Day on August 31, 1957. Each school must use the same curriculum set by the Ministry of Education, and the ministry is the ultimate decision maker for any educational plans, curriculum, or assessment (Ministry of Education, 2005).

Science is taught in Malay, but some teachers may still use English because in 2003, the Malaysian government implemented a policy of using

English for teaching science and mathematics. However, the policy ended in 2012, so Malay is now the standard.

National curriculum. The physics curriculum in Malaysia is standardized nationwide. The aims of the curriculum are “to provide students with the knowledge and skills in science and technology and enable them to solve problems and make decisions in everyday life based on scientific attitudes and noble values” (Ministry of Education, 2005, pp. 2).

In general, the national curriculum suggests several teaching and learning strategies: (1) open inquiry, (2) constructivism, (3) science, technology, and society, (4) contextual learning, and (5) mastery learning. Specifically, it suggests use of several teaching and learning methods: (1) experiments, (2) discussion, (3) simulation, (4) projects, (5) visits, and (6) use of technology (Ministry of Education, 2005, pp. 11-13). These teaching and learning strategies and methods are general and not specifically to be used for any topic. They are recommended but not required. The ministry intends the teaching and learning strategies and methods to emphasize thoughtful learning where students’ creative and critical thinking skills are to be developed and not be limited to rote learning.

The national curriculum consists of nine learning areas and all of them are required to be taught. One of the areas is Force and Pressure with six topics: Pressure, Pressure in Liquid, Atmospheric and Gas Pressure, Pascal’s Principle, Archimedes’ Principle, and Bernoulli’s Principle. For this study, Archimedes’ principle was chosen as the topic of investigation.

Archimedes' principle. Table 2 shows the details of the topic of Archimedes' principle taken literally from the national curriculum specifications.

Table 2

National Curriculum Specifications on Archimedes' Principle for the Form Four Physics Curriculum (or Grade 11 Equivalent)

Learning Outcomes	Suggested Learning Activities
<p>(a) Explain buoyant force. (b) Relate buoyant force to the weight of the liquid displaced. (c) State Archimedes' principle. (d) Describe applications of Archimedes' principle. (e) Solve problem involving Archimedes' principle.</p>	<p>Carry out an activity to measure the weight of an object in air and the weight of the same object in water to gain an idea on buoyant force.</p> <p>Conduct an experiment to investigate the relationship between the weight of water displaced and the buoyant force.</p> <p>Discuss buoyancy in terms of:</p> <p>(a) An object that is totally or partially submerged in a fluid experience a buoyant force equal to the weight of fluid displaced.</p> <p>(b) The weight of a freely floating object being equal to the weight of fluid displaced.</p> <p>(c) A floating object has a density less than or equal to the density of the fluid in which it is floating.</p> <p>Research and report on the applications of Archimedes' principle, e.g., submarines, hydrometers, hot air balloons. Solve problems involving Archimedes' principle.</p> <p>Build a Cartesian diver. Discuss why the diver can be made to move up and down.</p>

(Reproduced from Ministry of Education, 2005, pp. 29-30)

The national curriculum requires specific learning outcomes for teaching Archimedes' principle. As Table 2 indicates, teachers should teach about: (1) buoyant force, (2) the weight of liquid displaced, (3) the definition of Archimedes' principle, (4) applications of the principle, and (5) problem solving related to Archimedes' principle.

In terms of teaching and learning activities, the national curriculum recommends that teachers conduct: (1) an investigation about the apparent loss of weight of an immersed object in a liquid, (2) an investigation about the weight of liquid displaced by the immersed object, (3) discussion about Archimedes' principle, flotation, and submersion, (5) student research on applications of Archimedes' principle like submarines, hot air balloons, and hydrometers, and (6) physical model building – namely, building of a Cartesian diver. These teaching and learning activities are recommended and not required to be carried out. The national curriculum recommendations regarding teaching and learning activities of Archimedes' principle seem to have a specific order whereby it suggested that teachers teach the idea of the apparent loss of weight of an immersed object in a liquid as the first idea, followed by the idea of weight of liquid displaced by the object, and then the ideas of flotation and submersion later.

National assessment. The Ministry of Education through the Malaysian Examination Syndicate (*Lembaga Peperiksaan Malaysia – LPM*) determines the national physics examination questions which is administered at the end of high school education, usually every November and December. Each of the students

takes this exam once. All of the questions are based on the learning outcomes mentioned in the national physics curriculum. The exam consists of three papers.

Paper 1. Paper 1, with 50 questions, consists of multiple-choice questions and students sit for this paper for an hour and 15 minutes. The paper usually covers many topics, not only Archimedes' principle. Every year from 2008 to 2014, questions included Archimedes' principle except for 2012 (Ministry of Education, 2015).

Paper 2. Paper 2 consists of open-ended, structured, essay questions. Students sit through this part of the exam for two hours and 30 minutes. Topics covered are more specific compared to Paper 1 covering only selected topics with 10 main questions. Each main question also has follow-up questions. From 2008 to 2014, Archimedes' principle was only assessed in 2009, 2010, and 2013 (Ministry of Education, 2015). The questions are mainly about applications of Archimedes' principle. For example, a question in Paper 2 in 2010 asked students to design a raft for a raft competition that could move quickly in water and could accommodate 15 participants.

Paper 3. Paper 3 requires written responses to plan an experiment from a given context. Malaysian students sit for this paper for one hour and 30 minutes. From 2008 to 2014, Archimedes' principle was assessed in 2009, 2011, 2012, and 2014 (Ministry of Education, 2015).

This national examination is a high-stakes examination that determines a student's educational and career path after high school. Students who receive

excellent results in physics could become science majors at the pre-university education level and then go on to be science majors at the tertiary education level (college or university).

State and local context. This study was done in Johor, the southern state of the Malaysia Peninsula. Johor is a developing state with a hugely progressive main city, Johor Bahru, which is the capital of the state. Specifically, this study was conducted in two districts with upper class and middle-class people working as government officials and private sector workers. Both districts are well developed due to many industrial and business investments and are influenced by Singapore, Malaysia's neighbor.

Johor State Education Department takes the lead in implementing the national education policies set by the Ministry of Education. The education departments' plans need to fit the ministry's plan because the ultimate power of educational policy making is placed in the hands of the federal government, not the state government, according to the national constitution. The State Education Department plays a great role in ensuring that the current Malaysian Education Blueprint 2013-2025 is well implemented at the state level (Ministry of Education, 2013). In addition, the Office of District Education is placed in each district of Johor. The office needs to work closely with the State Department of Education to implement the recent national education blueprint.

School context. This study was conducted at three public schools funded by the federal government in Johor, Malaysia. Each school adopts the national

curriculum for their physics curriculum. Schools give teachers freedom on how to teach students based on what they deem appropriate. It is also up to teachers what teaching activities to use. At the school level assessment, physics teachers follow the question format used in the national exam. The Ministry of Education releases a book each year that has the previous year's physics questions. The book helps physics teachers construct questions for exams at the school level by following the format of the national exam papers and question types: objective questions, structural questions, and essays or open-response questions. School-level examinations are designed by the teachers of a subject such as physics and are given school wide. A physics teacher can decide whether or not to give their own examinations or tests to their students in a class since they are optional depending on the teacher's initiatives.

The first school in this study (School C) is an urban school and is one of top schools in Johor where most students have a very high academic performance level. The second school (School A) is also among the top schools in Johor with students who are mostly have above-average performance and have great potential to excel in the national examination. The third school (School B) has an above average performance level with students who are likely to pass, but not excel in the national exam.

Research Design

This study aimed to characterize physics teachers' pedagogical content knowledge (PCK) in practice, particularly main ideas, teaching activities and

representations, and reasons for adopting those activities and representations including contextual knowledge. The model of integrative pedagogical content knowledge (PCK) (Gess-Newsome, 1999) was used as the framework. It consists of three types of knowledge: (1) subject matter knowledge, (2) pedagogical knowledge, and (3) contextual knowledge and integrations of the knowledge. This model was utilized because it could capture the three types of knowledge and interactions among them when the teachers teach Archimedes' principle in real classroom settings.

This study employed a multiple-case study design (Merriam, 1998). This design was appropriate because it can provide rich descriptions of the three physics teachers' classroom practices, main ideas of Archimedes' principle, teaching activities and representations, and reasons for adopting particular activities of teaching and representations.

Multiple data sources were used to obtain data on classroom teaching practices and reasons for using them including classroom observations, audio recordings of teaching, interviews, and documents related to the teaching of Archimedes' principle. Classroom observations and audio recordings of teaching can provide data on the main ideas presented in class on Archimedes' principle, teachers' classroom practices, and representations of the main ideas. Interviews can give data on teachers' reasons for using particular teaching activities. Documents like lesson plans, written questions given to students, notes, slides,

and photos of classroom activities can also supplement descriptions of teachers' teaching.

This study had three cases with each physics teacher being an individual case. Analysis across cases was possible since they taught the same physics curriculum and were teaching in the same academic year of 2015. Using only three cases is reasonable because a qualitative approach usually uses a small number of participants. Ideally, this study aimed to study four participants. However, due to a schedule conflict between the fourth teacher and the other three teachers, the fourth case could not be studied. Thus, only three cases were available for this study.

Participant Selection

This study adopted a criterion-based sampling method (Merriam, 1998) to ensure that each participant had similar characteristics. The criteria to select the participants were that (1) they have at least a bachelor's degree in physics education, (2) they have taught physics for at least three years, (3) they were currently teaching physics at the form four level, and (4) they were currently teaching the topic of Archimedes' principle. All of these criteria were important to ensure that each physics teacher had a solid mastery of physics subject matter, had gained adequate teaching experience that was essential for developing their own style of teaching, and were very familiar with Archimedes' principle.

In the beginning, snowball sampling was utilized. The researcher of this study identified potential participants based on professional contacts in Malaysia

from the researcher's past contacts during a science teacher education program. The potential participants were asked to recommend other names that fit the criteria if they did not fulfill the criteria or did not want to be involved in this study.

Initially, eight potential participants were contacted through Facebook and phone calls. They were all physics teachers, except for one participant who was a physics teacher educator. The participant who was not a physics teacher suggested a new person who was a physics teacher and agreed to participate. Four potential participants did not agree to participate because of heavy workloads at their schools and because they did not currently teach physics at the form four level (Grade 11). Of the four possible participants who remained, three participants who taught physics at different schools could be studied without scheduling conflicts. Table 3 shows the characteristics of the participants: Aminah, Aishah, and Ali.

Table 3

Characteristics of Participants

Characteristics	Aminah	Aishah	Ali
School	A	B	C
Degree(s)	B. S. Physics Edu. Comp.*	B. S. Physics Edu.**	M. Ed. Physics ***B. S. Physics Edu.**
Teacher Education Program	University A	University A	University A
Years of Teaching	8	6	7
Physics School Location	Suburban	Suburban	Urban
Class Size	31	30	35
School Type	Public	Public	Public

Note. *Bachelor of Science with Education and Computer (Physics), **Bachelor of Science with Education (Physics), ***Master of Education (Physics)

All participants shared some common characteristics in addition to the selection criteria. They all completed the same teacher education program at University A and taught in public schools.

Conceptual Framework

This study used the integrative model of PCK (Gess-Newsome, 1999) which includes three types of knowledge: (1) subject matter knowledge, (2) pedagogical knowledge, and (3) contextual knowledge (see Figure 1). The data collection in this study covered all three types of knowledge. Teachers' subject matter knowledge, which included the main ideas of Archimedes' principle, was captured through classroom observations, audio recordings of teaching, and documents collected. Their teaching activities and representations were also captured using the same methods. Interviews were also conducted to obtain data

on teachers' reasons for using particular teaching activities. The same methods, interviews, were used to obtain data on contextual factors that might shape teachers' practices.

Data Collection

Data collection mainly used the native language, Malay, considering that the teachers were more comfortable interacting in their native language than in English. Data were collected during the second part of the schooling year of 2015 from June 24, 2015 to September 2, 2015. Methods included audio recordings of teaching, classroom observations, individual semi-structured interviews, and collection of documents. Table 4 shows the timing of the data collection.

Table 4

Timing of Data Collection

Participants	Activities	Date
Ali	Pre-teaching interview	June 24, 2015
	Audio recordings of teaching and classroom observations	July 22, July 23, and July 29
	Post-teaching interview	August 23, 2015 and August 26, 2015
Aminah	Document collection	August 26, 2015
	Pre-teaching interview	June 23, 2015
	Audio recordings of teaching and classroom observations	July 27, 2015, and July 28, 2015.
Aishah	Post-teaching interview	August 18, 2015 and August 22, 2015
	Document collection	August 22, 2015
	Pre-teaching interview	June 29, 2015
	Audio recordings of teaching and classroom observations	August 17, 2015 and August 24, 2015
	Post-teaching interview	August 30, 2015 and September 2, 2015
	Document collection	September 2, 2015

The audio recordings of teaching and classroom observations were made according to each teacher's instructional time while teaching Archimedes' principle.

Pre-teaching interview. These interviews lasted about one hour for each teacher using an individual semi-structured interview method. Pre-teaching interviews can provide data on teachers' knowledge on contextual factors such as national curriculum and assessment, their goals of teaching physics, and typical

teaching activities for teaching this topic. Here are the main questions asked in the interviews:

- (1) What are your goals when you teach physics?
- (2) How do you usually do your teaching?
- (3) How do you assess the students' learning?
- (4) Do national policies, practices and guidelines influence what you teach? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?
- (5) Do national policies, practices and guidelines influence how you teach? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?
- (6) Do national policies, practices and guidelines influence how you assess students' learning? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?
- (7) Do school policies, practices and guidelines influence what you teach? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?
- (8) Do school policies, practices and guidelines influence how you teach? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?

(9) Do school policies, practices and guidelines influence how you assess the students' learning? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?

The full version of questions asked is in Appendix A. The interviews were recorded and transcribed. During the interviewing process, follow-up questions and then more probing questions were asked to better understand their responses to the main questions.

Classroom observations and recording teaching. When teachers' instruction was given and recorded, the researcher took observation notes focusing on the teachers' instructional objectives, contents of teaching and teaching activities. Generally, this field note taking method was somewhat freestyle where no particular protocols were adopted, mainly because the aim of note taking was to record the general flow of teaching. The details of their teaching were recorded through audio recordings, so the observation notes were complementary to the audio recordings of teaching.

Each teacher's instruction on Archimedes' principle was recorded using a voice recorder, which was given to each teacher before the class. The voice recorder was intended to record what the teachers were saying, but some students' voices were also included when teachers interacted with students. Only teachers were provided with the voice recorder, and students were not. The audio recordings of teaching were then transcribed. Since the voice recorder had

recorded each instruction, the recorder provided details of what teachers were teaching.

Post-teaching interviews. The post-teaching interviews were meant to go into further depth about the teachers' classroom practices, especially their reasons for using particular teaching activities and contextual factors that informed their practices. Two post-teaching interviews were conducted for each teacher. Here are the main questions asked during the post-teaching interview I:

- (1) What were your goals when you taught the Force and Pressure unit? Why did you set those goals?
- (2) Describe how you did your teaching about Force and Pressure unit? Why did you teach that way?
- (3) Did you assess what the students learned about Force and Pressure unit? How did you do that?
- (4) Did national policies, practices and guidelines influence what you taught about the Force and Pressure unit? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?
- (5) Did national policies, practices and guidelines influence how you assessed students' learning about the Force and Pressure unit? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

- (6) Did school policies, practices and guidelines influence what you taught about Force and Pressure unit? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?
- (7) Did school policies, practices and guidelines influence how you taught about Force and Pressure? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?
- (8) Did school policies, practices and guidelines influence how you assessed the students' learning about Force and Pressure? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

Appendix B provides the full version of questions in the post-teaching interview I. The questions in the post-teaching interview I were meant to understand the teachers' goals of teaching and how these goals might be connected to other contextual factors like curriculum and assessment. All interviews were recorded and transcribed.

The post-teaching interview II was then conducted once. The questions were mainly about teachers' reasons for using particular teaching activities, and other factors that might shape their practices of teaching Archimedes' principle. Here are the main questions asked in the post-teaching interview II:

- (1) In my notes, I did not see that you used an experiment when teaching Archimedes' principle. Could you tell me what the possible challenges of not using experiment? (Aminah)

(2) I found that you did not conduct experiment when teaching the topic of Archimedes' principle. Could you tell me why? (Ali)

(3) Based on my notes, I saw that you conducted experiment activities when teaching Archimedes' principle. Why did you think that activities might be suitable for the students? (Aishah)

Appendix C provides the full version of the questions. Each teacher was asked questions about their teaching activities when teaching Archimedes' principle. They were asked why they adopted their particular activities and were also questioned about why they did not adopt activities that were recommended by the national curriculum such as experiment (in Aminah's and Ali's case).

Table 5 shows the data matrix of this study.

Table 5

Data Matrix

Research Questions	Main PCK Components	Primary Data Sources
How do physics teachers teach Archimedes' principle?	Pedagogical knowledge Subject matter knowledge	Audio recordings of teaching Observation notes Collection of documents
Why do physics teachers teach Archimedes' principle the ways they teach?	Pedagogical knowledge Contextual knowledge	Pre-teaching interview Post-teaching interview I Post-teaching interview II

The first research question was mainly answered using the constructs of pedagogical knowledge and subject matter knowledge. The main data sources were audio recordings of teaching, observations notes, and documents collected included slides, written questions given to students, notes, photos of classroom activities, and lesson plans. For the second research question, the main constructs were pedagogical knowledge and contextual knowledge. The primary data sources were interviews: pre-teaching interview, post-teaching interview I, and post-teaching interview II.

Data Analysis and Validation

The conceptual framework of this study (Figure 1) was used to guide the data analysis. However, it was also inductive, at least in part, to allow for discovery of unexpected findings that could inform the research questions. This study then took into count these possible findings.

The general steps of analyzing data were:

- (1) Creating codes for each data source in each case (individual teacher), and each code was given a unique ID that identified the source of the codes (see Table 6). The codes were in English, while data sources were originally in Malay.
- (2) Episode making and triangulation.
- (3) Amplifiers and filters and triangulation.
- (4) Member checking and revising descriptions of cases.

(5) Conducting cross-case analysis using the constant comparative analysis method.

(6) Making themes across cases.

The steps from (1) to (4) involved analysis within cases, including validation, whereas cross-case analysis was used for (5) and (6) (Merriam, 1998; Saldana, 2013).

Code making. The ideas involved in Archimedes' principle were used to make codes for ideas the teachers were to teach. The codes were developed based on the framework of the national curriculum specification of content (Ministry of Education, 2005) and the explanation of buoyancy phenomena by Hewitt (2002).

Four main ideas were identified. The codes and the associated ideas were:

Idea A: The weight of liquid displaced by an immersed object is equal to the buoyant force.

Idea B: The apparent loss of weight of an immersed object in a liquid is equal to the buoyant force.

Idea C: In a flotation case, the weight of an object is equal to or less than the buoyant force.

Idea D: In a submersion case, the weight of an object is greater than the buoyant force.

Data on the main ideas primarily came from the audio recordings of teaching and documents collected.

Teaching activities were coded from the audio recordings of teaching as well as from the observation notes. Codes were created based on the recommended teaching activities proposed by the Ministry of Education (2005): lab work, discussions, and model building. However, other teaching activities were also coded using suggestions from the literature including lectures, questioning, and demonstrations (Treagust & Tsui, 2014).

Regarding the reasons for using particular teaching activities, the data were coded mainly from interviews, and part from audio recordings of teaching. Scholars have mentioned several reasons for using a particular teaching activity such as Treagust and Tsui (2014) who suggested that teachers use questioning to understand students' current ideas. However, this study relied on the actual reasons that the teachers reported from their own classroom teaching experience. For example, Aminah mentioned that she used lectures because she wanted to teach students how to answer exam questions. This reason was coded as "lectures – exam preparation."

Regarding representations used to teach the main ideas, eight modes of representations were coded: (1) verbal symbols (VS), (2) written symbols (WS), (3) pictures (P), (4) real-life situations (RLS), (5) manipulatives (M), (6) formulae (F), (7) tables (T), and (8) graphs (G) (Cramer, 2003; Lesh & Doerr, 2003). Then, the sequences of translations of modes of representations were developed for each teacher. The sequences covered across and within modes of representations where the teachers moved from one representation to another when teaching an idea.

Representations used and their translations across and within modes were coded from the audio recordings of teaching, observation notes, slides, written questions given to students, books used, notes, and photos of classroom activities (e.g., student posters and lab equipment).

Each code created was given a unique ID so the source of the code could be easily tracked. Table 6 shows the unique IDs given and the respective codes.

Table 6

Unique IDs for Codes

Data Sources	Unique ID		
	Aminah	Aishah	Ali
Lesson Plans	AM-DOCLP- Date-Code Number	AI-DOCLP- Date-Code Number	AL-DOCLP- Date-Code Number
Photos	AM-DOCPH- Date-Code Number	AI-DOCPH- Date-Code Number	AL-DOCPH- Date-Code Number
Slides	AM-DOCSL- Date-Code Number	-	AL-DOCSL- Date-Code Number
Module	AM-DOCM- Date-Code Number	AI-DOCM-Date- Code Number	AL-DOCM-Date- Code Number
Pre-Teaching Interview	AM-PREIN- Date-Code Number	AI-PREIN-Date- Code Number	AL-PREIN-Date- Code Number
Post-Teaching Interview (I)	AM-POSTIN1- Date-Code Number	AI-POSTIN1- Date-Code Number	AL-POSTIN1- Date-Code Number
Post-Teaching Interview (II)	AM-POSTIN2- Date-Code Number	AI-POSTIN2- Date-Code Number	AL-POSTIN2- Date-Code Number
Observation Note	AM-OBS-Date- Code Number	AI-OBS-Date- Code Number	AL-OBS-Date- Code Number
Audio Recordings of Teaching	AM-VOR-Date- Code Number	AI-VOR-Date- Code Number	AL-VOR-Date- Code Number

Note. AM: Aminah, AI: Aishah, AL: Ali, DOCLP: documents from lesson plans, DOCPH: photos, DOCSL: slides, DOCM: modules, PREIN: pre-teaching interview, POSTIN1: post-teaching interview I, POSTIN2: post-teaching interview II, OBS: observation notes, VOR: audio recordings of teaching.

Episode making and triangulation. Teaching episodes were primarily developed based on how the teachers organized the main ideas and were ordered chronologically based on the actual flow of the teachers' teaching. The order of

teaching the ideas was important for understanding ways of organizing the main ideas in practice. The lengths of the overall teaching episodes varied across teachers depending on how much time they spent for teaching Archimedes' principle. The more time they allocated, the longer their episodes.

Two main elements were presented in a particular episode: (1) teaching activities and (2) representations used. The teachers' teaching activities and representations were described based on how they taught a particular idea. In a specific episode, the teachers might use one or more teaching activities and representations. Direct quotes from audio recordings of teaching and photos of teaching activities, slides, notes, and written questions were used to describe how the teachers taught a specific idea in an episode.

A particular episode served as a triangulation point. Data from audio recordings of teaching, observation notes, and documents were gathered. This type of triangulation made each episode rich and reliable because a particular episode was built from multiple sources of data.

An excerpt from Ali's case shows how different data sources were used.

Teaching episode 1: Introduction. In the first lesson, Ali introduced students to Idea A of Archimedes' principle – the weight of liquid displaced by an object is equal to the buoyant force (Objective 1). He used lecture and questioning activities.

Representations used were verbal symbols, written symbols, a picture, and a real-life situation.

Ali initially lectured about Idea A.

Archimedes' principle states that the upward buoyant force on a submerged object is equal to the weight of the liquid that is displaced by the object.

[Code: AL-VOR-July 22-1 & AL-VOR-July 22-2]

He literally read the slide that showed Idea A. Figure 2 shows the slide.

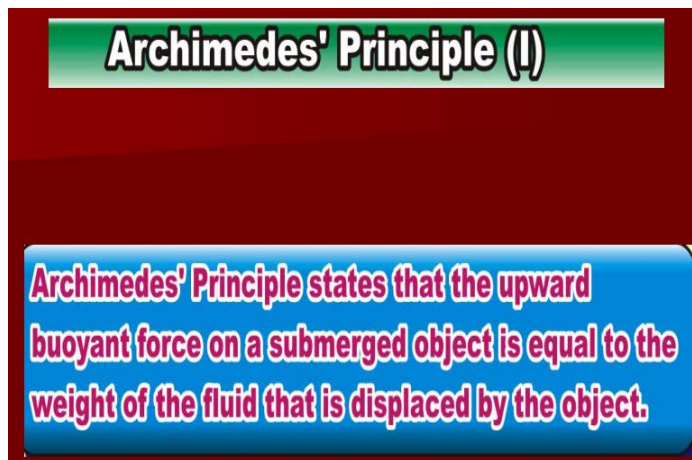


Figure 2. Idea A of Archimedes' principle.

[Code: AL-DOCSL-July 22-2]

The lecture was the verbal representation, and the slide was the written representation.

Ali continued teaching Idea A using the questioning activities. He dialogued with students and used a slide (Figure 3) to assist in the dialogue.

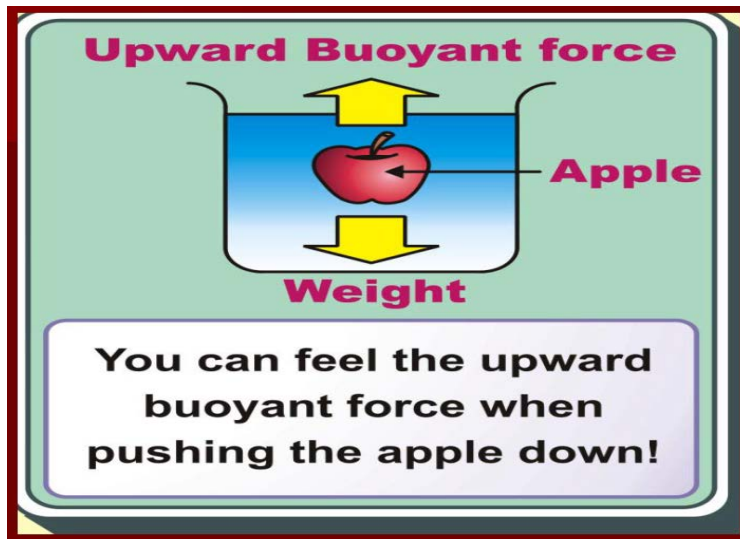


Figure 3. The weight of liquid displaced.

[Code: AL-DOCSL-July 22-1]

Figure 3 was the written, picture, and real world situation representations.

Ali: Can you understand the statement in the first slide (Figure 2)?

Student₁: No.

Ali: OK. Let's say, I change the statement into a diagram (Figure 3). I place an apple into a beaker. There are two forces acting on the apple. The first is the weight, W . Another is the buoyant force. The apple seems to float. Before I place the apple into water, there is just water. Then, if we place the apple or an object, what happens to the water?

Student₂: It is pushed.

Ali: OK. If the beaker is very small, the water will flow out or be displaced. The water is displaced. We call it "displaced water." If

we measure the displaced water, then the weight of the water displaced is equal to what?

Student₂: The apple's weight.

Ali: It is equal to the buoyant force.

Student₃: Oh.

Ali: You can feel the upward buoyant force when pushing the apple down into the water. The first idea of Archimedes' principle is the weight of water displaced is equal to the buoyant force.

[Code: AL-VOR-July 22-5]

The dialogue was the verbal representation.

From the above example, the data used for creating episode 1 for Ali came from audio recordings of teaching (like Code: AL-VOR-July 22-1 and AL-VOR-July 22-2) and slides (like Code: AL-DOCSL-July 22-2 and AL-DOCSL-July 22-1).

Amplifiers and filters and triangulation. The codes of reasons for using particular teaching activities were categorized based on the notion of “amplifiers and filters” (Gess-Newsome, 2015). Categories created included (1) personal amplifier, (2) personal filters, (3) contextual amplifiers, and (3) contextual filters. For example, the codes of “preparing students for exams” and “finishing teaching the national syllabus” were categorized as “contextual amplifier,” while the codes of “heavy workloads” and “shortage of laboratory supplies” were categorized as “contextual filter.” Triangulation of the data was conducted using three sources of interview data: the pre-teaching interview, the post-teaching interview I, and the

post-teaching interview II. An example of triangulation is presented below for Ali's case.

Personal amplifiers. Ali indicated that he wanted students to be able to apply physics knowledge into their real lives. He mentioned that physics is a subject that has a close connection with students' lives. By linking physics to their world, they can understand those applications using the physics knowledge they learned at their school. Ali stated that:

My goal of teaching physics is to make students be able to relate their real lives with science. We know that science is wide, and physics is one of science branches. Physics is close to students' surrounding phenomena. Thus, students need to know why a particular phenomenon can occur. The unit of Force and Pressure (containing Archimedes' principle) is also closely connected to students' real world. By learning this unit, students can strengthen their understandings of physical phenomena around them.

[Code: AL-PREIN-June 24-1, AL-PREIN-June 24-2, AL-PREIN-June 24-3, AL-POSTIN1-Aug 23-2, & AL-POSTIN1-Aug 23-3]

Ali's words were taken from the pre-teaching interview data (like Code: AL-PREIN-June 24-1, AL-PREIN-June 24-2) and post-teaching interview data (like Code: AL-POSTIN1-Aug 23-2, & AL-POSTIN1-Aug 23-3). These various IDs showed that data came from different interviews.

Member checking and revision of case descriptions. When the writing of each case was completed, the researcher sent the descriptions to each teacher for the member checking process. They were asked to check the sentences and quotes that were used in the descriptions, to verify the meanings of any words used by the researcher in the descriptions, and to correct any sentences that they thought were not true or were inaccurate. Overall, they were satisfied with the descriptions.

Conducting cross-case analysis. Cross-case analysis is presented in Chapter 5. The chapter was organized according to two research questions. The first question of “how do physics teachers teach Archimedes’ principle in real classroom settings?” was answered primarily by using the constructs of subject matter knowledge and pedagogical knowledge because they could explain the teaching activities and representations that the teachers used. The first section is about the main ideas used in teaching Archimedes’ principle across the teachers and their ways of organizing the ideas in each teacher’s teaching episode. A table was created to summarize the ways of organization. Organization covered: (1) the order of teaching specific ideas, (2) the emphasis in teaching specific ideas, and (3) the combination of ideas in certain episodes.

The second section was about the teaching activities that the teachers used. Teaching activities of each teacher and their main characteristics were presented and compared.

Then, the third section was created to include multiple representations used across the teachers. Translations of representations were made solely for Idea A and its associated ideas in certain episodes. The reason was Idea A was the most general idea of Archimedes' principle that served as the basis of other ideas, and thus it was the most important idea. The researcher followed the following steps in analyzing the translations of representations across the teachers:

- (1) The researcher referred back to descriptions of teaching practice in Chapter 4 for each teacher and constructed understanding of the flow of teaching in each episode that consisted of Idea A and the related ideas.
- (2) The researcher marked the flow of teaching in the relevant episodes using the following symbols: (1) written symbols (WS), (2) verbal symbols (VS), (3) manipulatives (M), (4) real-life situations (RLS), (5) pictures (P), (6) formulae (F), (7) tables (T), and (8) graphs (G).
- (3) If a representation came from students, then it was marked using a subscript of s . For instance, V_s .
- (4) The subscripts of $1-9$ indicated the sequence of use of a particular representation in a particular episode. For instance, F_1 and then F_2 mean that the F representations are the same representation of F but it was used for the first and second time in an episode.
- (5) The subscripts of $a-d$ mean that two or more representations are from the same mode like F but they are different representations. For instance, F_a and F_b mean the F representations were two different formulae.

- (6) Then, a complete sequence of representation translations of a particular episode was made. For instance, in episode 2 of Aminah's case, the complete sequence of representation was: $WS_{a1} \rightarrow VS_{a1} \rightarrow RLS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1}$. This complete sequence means that Aminah started teaching episode 2 with a written representation and then she moved to using a verbal representation. After that, she moved to using a real-life situation representation and moved to a verbal representation for the second time. Finally, a student of Aminah asked a question verbally, which completed the translation in the episode.
- (7) When the complete sequences of representation translations of the relevant episodes of each case were done, the researcher made a table summarizing the whole cases' findings.
- (8) The researcher made comparisons for each case to see main patterns of the sequence of representations. The comparisons emphasized the common features of the sequence of representation translations. The main reason for finding these patterns was to identify key representations that could primarily shape the translations of representations.

After that, the researcher developed the part for answering the second research question: Why do physics teachers teach Archimedes' principle in the ways they do? The construct of contextual knowledge was mainly used to answer this question. Contextual knowledge in the teachers' practices explained the reasons for their subject matter knowledge and pedagogical knowledge applied in

their teaching episodes. The first section was about the reasons for teaching the main ideas across the teachers. The second section was about the reasons for organizing the main ideas in practice. The third section provided the reasons for using specific teaching activities and the final section revealed the reasons for translating the representations as the teachers did.

Creating Themes. When cross-case analysis was completed, the researcher found similarities and differences that were used as the basis for creating themes. Themes are presented in Chapter 6 and were created to answer the two research questions. Similarities of findings across the teachers (cases) were emphasized to develop the themes. The themes were matched with the conceptual framework.

Background and Roles of the Researcher

This section is important to tell readers how the background of the researcher could help him conducting this study, with regard to his academic and career background. For example, his background in physics education helped him understand Archimedes' principle easier.

The researcher is a Malaysian who was born in the mid-1980s and completed his primary and secondary education in Malaysia from 1993 to 2003. His view on education is largely shaped by the Malaysian educational system that practices a centralized education system where both the national curriculum and the national assessment are standardized. He also went to a matriculation college in Malaysia to prepare for university education.

In 2005, the researcher started his undergraduate education at a university in Johor, Malaysia studying for a Bachelor of Science in Education (Physics). He took courses in physics education, educational philosophy, pedagogy, educational psychology, educational sociology, university physics, and general subjects such as ethnic relationships. He completed an internship for three months in a secondary school in Johor, Malaysia where he had the opportunity to teach topics such as Archimedes' principle and Bernoulli's principle. His personal thought was that lab work and discussion are important activities when teaching a complex topic like Archimedes' principle, so he taught using both lab work and discussion with students.

During the final year of his undergraduate education, he conducted a simple study of three preservice physics teachers' subject matter and pedagogical knowledge during one microteaching lesson. While observing how preservice teachers taught physics in microteaching classes, he realized that some teachers were articulate in teaching physics, while others were less articulate due to a lack of communication skills.

When the researcher completed his undergraduate education in 2009, he planned to be a schoolteacher, but changed his plan when a university offered and he accepted an academic position as a tutor. At the same time, he enrolled in a master's degree program in physics education at the same university where he was working. He took courses specifically on physics education and science education including physics teaching methods, science curriculum, and science

education assessment. He also wrote a thesis on preservice physics teachers' technological, pedagogical, and content knowledge (TPACK) emphasizing the conception of Archimedes' principle as the subject matter in TPACK. He found that many preservice teachers had alternative conceptions of Archimedes' principle.

After completing his master's degree in 2011, he continued working as a tutor at the university, which exposed him to academia work such as advising students, research, teaching, and professional services. These experiences helped him understand the nature of academia, and in 2013, he was accepted into the Ph.D. program in science, technology, engineering, and mathematics (STEM) education at the University of Minnesota. He is particularly interested in teaching methods and the conception of Archimedes' principle so he has continued to research PCK and Archimedes' principle. His background in these two areas has helped him understand and study these areas at a deeper level.

Chapter IV: Single Case Analysis

This chapter presents and analyzes each case separately – Aminah, Aishah, and Ali. The descriptions of these cases start with that of Aminah, followed by the cases of Aishah and Ali. The structure of each case is: (1) a brief description of the teacher's background, (2) a description of her or his physics class, (3) a detail description of her or his classroom practices related to the teaching of Archimedes' principle including teaching activities and representations of content, (4) each teacher's main characteristics of teaching activities, (5) each teacher's main characteristics of translation of representations in selected episodes, and (6) amplifiers and filters that explain each teacher's reasons for her or his classroom practices. The detailed classroom practices section is presented as teaching episodes in chronological order.

Case I: Aminah

Aminah's background. Aminah received a bachelor's degree in physics education from a public university in Malaysia in 2007. For the following eight years, she has been teaching physics at the upper secondary school level (equivalent to Grade 11 and 12 in the US). Aminah teaches in a suburban school in a district in Johor, Malaysia. In 2015, Aminah received the title of "Excellent Physics Teacher" from the Ministry of Education due to her excellence in teaching Physics at the secondary school level. Throughout her service as a physics teacher, she has participated in several professional development

programs provided by the Ministry of Education including the use of inquiry-based learning.

Aminah's physics class. Physics is compulsory for students enrolled in the science stream. Aminah taught physics for two 60-minute periods each week as was assigned in the school schedule through a mixture of Malay, and English. While, Malay is the primary verbal language used, some curricular materials were available in both languages, but others like power point slides were mainly in English.

The focus of this study was buoyancy that was part of the larger Force and Pressure unit. Aminah allocated two days to teach the buoyancy topics (July 27, 2015, and July 28, 2015), which included three relevant principles: Pascal's principle, Archimedes' principle, and Bernoulli's principle. The teaching of Archimedes' principle is described completely below. The teaching of other principles is described briefly so that the context in which Archimedes' principle was taught is evident.

The primary curricular materials she used were presentation slides that she had purchased from a commercial company and written questions from a book she had purchased from another company. These curricular materials align with the specifications of the national curriculum.

Classroom practices. Aminah set three instructional objectives indicating what students should be able to do: (1) state the principle, (2) describe applications of the principle, and (3) solve problems regarding the principle.

These objectives came from the national curriculum [Code: AM-DOCLP-July 27-4, AM-DOCSL-July 27-13, AM-DOCM-July 28-1, AM-DOCM-July 28-2, AM-DOCM-July 28-3, & AM-DOCM-July 28-4].

Archimedes' principle was presented in Aminah's classroom in terms of four main ideas that she taught. Those ideas were:

Idea A: The weight of the fluid displaced by an object is equal to the buoyant force.

Idea B: The weight loss of an object is equal to the buoyant force.

Idea C: In the case of flotation, the weight of an object is equal to the weight of the fluid displaced by the object.

Idea D: In the case of immersion, the weight of an object is greater than the buoyant force.

[Code: AM-VOR-July 27-1, AM-VOR-July 27-4, AM-VOR-July 27-6, AM-VOR-July 27-7, & AM-VOR-July 27-8]

All ideas came from the national curriculum that explicitly suggests teachers teach these ideas.

Overall, Aminah utilized three activities for teaching the main ideas of Archimedes' principle: (1) small group exam practice, (2) lectures, and (3) questioning during whole class lecture. In all, Aminah spent around 33 minutes teaching the Archimedes principle in two lessons. She allocated 20 minutes for the activities of small group exam practice, 12 minutes for the lecture activity, and

1 minute for the questioning during whole class lecture activity. Her teaching is described in 11 episodes.

Teaching episode 1: Introduction. In this first lesson, Aminah began with an introduction by writing notes about Pascal's principle, Archimedes' principle, and Bernoulli's principle. She wrote the notes on the whiteboard, and asked students to copy the notes in their notebooks. She did not lecture the students while she did the writing on the board. The notes were about each principle's definition, the mathematical formula involved in the principles, and real-world applications of those principles. Regarding Archimedes' principle, she wrote the definition "the principle states that when an object is partially or totally submerged in liquid, the upthrust or buoyant force exerted on the object is equal to the weight of liquid displaced" (Objective 1). Then, she wrote the formula of the Archimedes' principle, $F = \rho Vg$, where F is the buoyant force, ρ is the density of a liquid, V is the volume of liquid displaced, and g is the gravitational acceleration. Real world applications she noted were submarines, hot air balloons, and hydrometers (Objective 2). Note writing and copying by students took around 26 minutes. She used approximately 10 minutes for Archimedes' principle, 9 minutes for Pascal's principle, and 7 minutes for Bernoulli's principle.

Teaching episode 2: Idea A. After completing writing the notes, she explained Pascal's principle for about 11 minutes. She talked about Pascal's principle definition, the formula of the principle, and applications like a hydraulic pump and a hydraulic jack.

She then moved to explaining Idea A of Archimedes' principle – the weight of the fluid displaced by an object is equal to the buoyant force. She gave lectures and used the questioning during whole class lecture activity for teaching Idea A. Her content representations were: (1) verbal symbols (VS), (2) written symbols (WS), and (3) real-life situations (RLS). Manipulatives (M), pictures (P), formulae (F), tables (T), and graphs (G) representations were not used.

Aminah briefly explained that the weight of fluid displaced is equal to the buoyant force by using a lecture (Objective 1).

Archimedes' principle states that when an object is partially or entirely submerged in liquid, the upthrust or buoyant force exerted on an object is equal to the weight of liquid displaced.

[Code: AM-VOR-July 27-1]

Aminah's lecture used VS and WS representations only. She was referring to the notes written on the whiteboard regarding the definition of Archimedes' principle while lecturing about the definition.

She then moved to using an activity of questioning during whole class lecture for teaching students Idea A. Aminah asked students some questions regarding the idea of the weight of liquid displaced. Here she used VS and RLS representations from Archimedes' life.

Aminah: Have you heard of Archimedes? He was a scientist, right?
He is the person who discovered this principle. Have you heard of it?

Student₁: Oooo.

Aminah: He filled his bathtub full of water. He then entered the bathtub abruptly. What happened then?

Student₂: Water moved from the bathtub.

Aminah: Yes! Water in the tub moved. So, he was curious about why the water displaced. Through his investigation, he found that the total weight of water displaced was equal to the buoyant force exerted on his body. The less forcefully the water is displaced, the smaller the buoyant force exerts on an object. If a thin man enters the water, the amount of water displaced is little. The more water that is displaced, the bigger the buoyant force.

[Code: AM-VOR-July 27-2]

One of Aminah's students was familiar with the story of Archimedes, the scientist who discovered the principle. Her student knew that when Archimedes jumped into a pool, the level of the pool's water increased and some amount of the water moved out. She said to her students that the total weight of water displaced by Archimedes' body was equal to the buoyant force exerted on his body. This questioning activity was very brief, lasting approximately one minute.

Teaching episode 3: Idea B. In the same lesson (lesson one), Aminah taught students Idea B – the weight loss of an object is equal to the buoyant force. She used the lecture activity. Representations used were: (1) VS, (2) WS, (3) P, (4) RLS, and (5) F, while M, T, and G representations were not evident.

She gave an extensive lecture about Idea B and used a slide as shown in

Figure 4 (Objective 1).

Bab 3 Daya dan Tekanan

Aplikasi Prinsip Archimedes

Daya Keapungan dan Berat Cecair Tersesar, Prinsip Archimedes

Berat batu di udara	= W_1N
Berat batu dalam air	= W_2N
Berat bikar kosong	= W_3N
Berat bikar dan air	= W_4N
Kehilangan berat batu	= $(W_1 - W_2)N$
Berat air yang tersesar	= $W_4 - W_3N$

Kehilangan berat batu

=

Daya keapungan

=

Berat air tersesar

$$(W_1 - W_2) = (W_4 - W_3)$$

Prinsip Archimedes menyatakan bahawa daya keapungan yang bertindak pada objek yang tenggelam adalah sama dengan berat cecair yang disesarkan oleh objek.

Teach – Fizik Tingkatan 4

Figure 4. An investigation of Archimedes' principle.

(Translation: *Penimbang spring* = spring balance; *Daya keapungan* = buoyant force; *berat cecair atau air tersesar* = the weight of fluid or water displaced; *prinsip Archimedes* = Archimedes' principle; *berat batu di udara* = weight of a stone in air; *berat bikar kosong* = the weight of empty beaker; *berat batu dalam air* = weight of the stone in water; *berat bikar dan air* = weight of the beaker and water; *kehilangan berat batu* = the weight loss of the stone; *berat air yang tersesar* = weight of water displaced)

[Code: AM-DOCSL-July 27-10]

Her full lecture regarding the slide in Figure 4 was as follows:

If we run an experiment like this, we hang an object from a Newton's spring. Thus you will get the reading of its weight, which is equal to W_1 . Let say W_1 is 10 N. Then we put the object into the water in the Eureka can. The Eureka tin has a particular hole to allow water to flow out from the can. We should first fill the Eureka can with water until the water level is exactly at the same level with the hole. When you put the object into the water, what happens? Water will be going up, right? It is like when you put ice into water, and the water level goes higher. Water that goes up will flow out of the Eureka can. The magnitude of the object's weight in water is now less than in air, and we put a label of W_2 . Let's say, if the new reading of the weight of the object in water is 8 N, where does 2 N go? Do you feel lighter in water when swimming? That is the case. An upthrust exerts on the object. It acts in the opposite direction with the weight of the object. The upthrust or the buoyant force makes us float. To calculate the amount of the buoyant force, we subtract 8 N from 10 N, so we get 2 N.

[Code: AM-VOR-July 27-4]

Aminah explained that there was the loss of weight of an object when it submerged in water. The weight loss – which can be measured using a spring

balance as indicated in Figure 4 – is equal to the magnitude of a buoyant force.

She continued to explain that a normal force in water acts against the immersing stone that makes the stone lose some of its weight. She said to students that if the stone has 10 N weight in air, it becomes 8 N in water. The weight loss, which is 2 N (by deducting 10 N with 8 N), is the magnitude of the buoyant force exerted on the stone in water. Therefore, the buoyant force is equal to the weight loss.

Teaching episode 4: Idea A. In the same lesson (lesson one), Aminah was back to teaching Idea A. She used the notes she wrote on the whiteboard regarding the formula of Archimedes' principle, $F = \rho Vg$. She used the lecture activity and used representations of VS, WS, P, RLS, and F. G, T, and M representations were not apparent.

Aminah's lecture on Idea A, particularly on the formula of the Archimedes' principle was:

The formula for the buoyant force is given as $F_B = \rho Vg$. This formula is not just applicable in immersion cases but is also in flotation cases: for example, floating planes and floating hot air balloons. Examples of immersion cases are diving activities and immersing submarines. All of them (immersion and flotation applications and situations) are included in the Archimedes' principle. OK. Rho, ρ , is the density of a liquid like the density of seawater and oil. Then, V is the volume of an immersed object. In a mathematical question, just calculate the volume of the immersed

part of the object. Understand? Just calculate the submerged part (she was sketching an object that was partially immersed in a liquid). The last one is gravitational acceleration, which is equal to 10 m s^{-2} . Today, I just want to explain the concept. We will do exercises tomorrow.

[Code: AM-VOR-July 27-5]

Aminah explained to students the formula of Archimedes' principle, $F = pVg$, where F is the buoyant force, p is the density of a liquid, V is the volume of the immersed part of an object, and g is the gravitational acceleration (Objective 1). She reminded students that the formula is applicable in immersion and flotation cases like the real-life applications of submarines and hot air balloons (Objective 2). However, she did not provide any example of questions involving quantitative measures of the formula $F = pVg$.

Teaching episode 5: Idea C and Idea A. In the same lesson (lesson one), Aminah taught Idea C and Idea A. She used the lecture activity. The representations used were: (1) VS, (2) WS, (3) P, and (4) RLS. F, M, G, and T representations were not used.

Aminah gave lectures about Idea C. She used a slide as shown in Figure 5. Aminah provided explanations that an object can float due to the buoyant force exerted on the object (Objective 1). In addition, she explained the idea of flotation where an object like a ship displaces seawater that is equal to its weight. Aminah then explained the Plimsoll lines, shown in Figure 5, to teach students the density

of liquids, particularly the density of different oceans, and how different densities affect the buoyant force (Objective 2). This is the Idea A regarding the weight of liquid displaced, specifically on the role of a liquid's density.

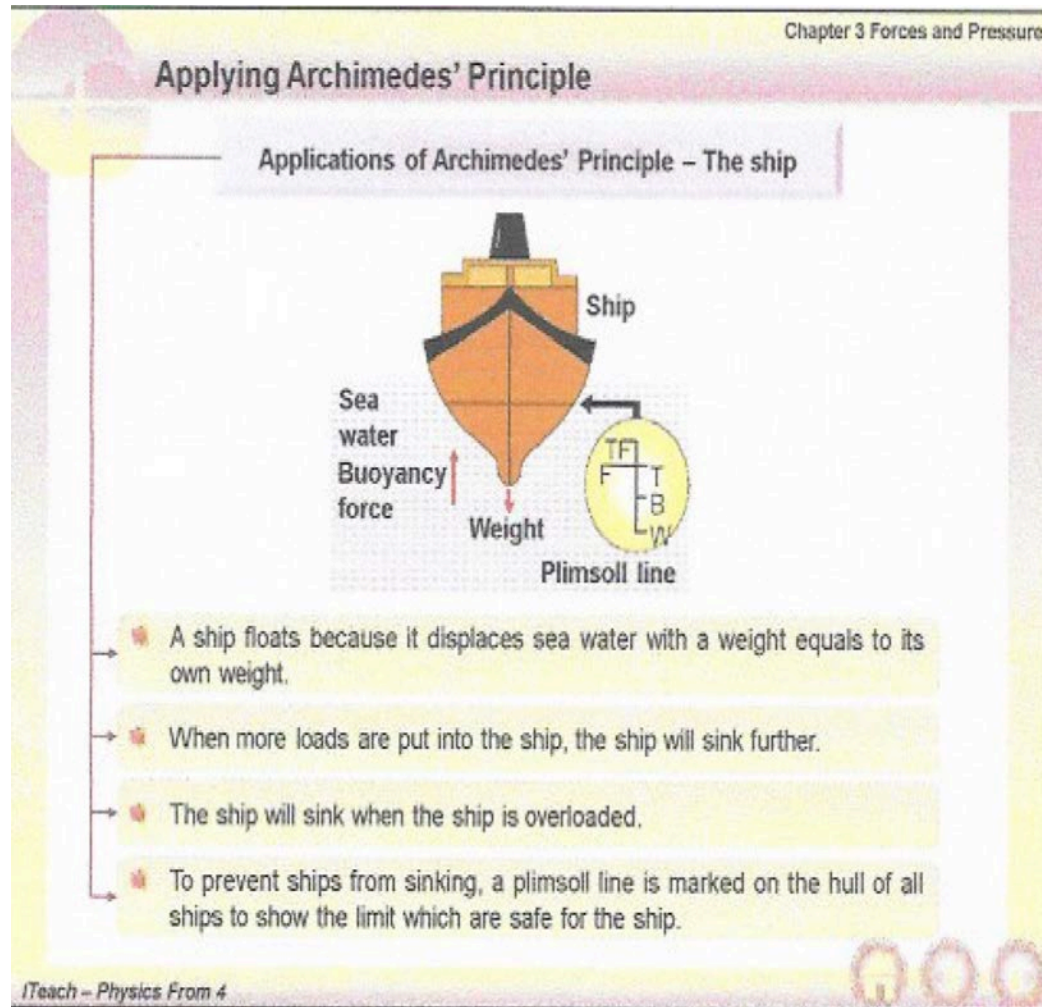


Figure 5. A ship and Plimsoll lines.

[Code: AM-DOCSL-July 27-12]

Aminah's entire lecture regarding flotation was:

An object can float because of the buoyant force. A ship (Figure 5) could float because it displaces seawater that is equal to its weight.

When a greater load is put on the ship, the ship will sink further. The more loads that are put on the ship, the more the ship will submerge because it displaces more seawater. So the ship will sink when it is overloaded. Plimsoll lines are used to prevent the ship from sinking. The lines are used as a guide to determine the maximum loads that the ship can bring. The buoyant force depends on the density of liquid. The higher the density, the higher the buoyant force. So, densities of seawaters are different. For instance, the density of the LCS, the Artic, and the Indian Ocean are different. Each of the oceans was set with a particular Plimsoll lines. For the LCS, the maximum line is B (see Figure 5). When the ship exceeds the B line, it sinks. The crews must throw out loads to ensure the ship does not sink. They must always check the lines.

[Code: AM-VOR-July 27-6 & AM-VOR-July 27-7]

Then, one of Aminah students asked her how to measure the density of seawater.

Student₁: Teacher, how to measure the density of the seawater?

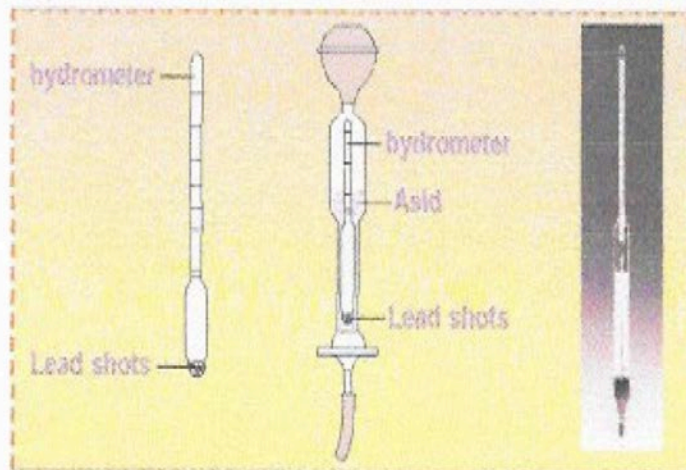
Aminah: We use hydrometers. This is the hydrometer (Figure 6).

This is a simple hydrometer. It is used to check car batteries.

Figure 6 shows the simple hydrometer.

Applying Archimedes' Principle

Application of Archimedes' Principle – The hydrometer



- The hydrometer is used to measure the relative density of a liquid.
- It is used to check the condition of a car battery by determining the relative density of the acid in the battery which is not supposed to fall below 1.20

Teach – Physics From 4

Figure 6. A simple hydrometer.

Teaching episode 6: Idea C and Idea D. In the same lesson (lesson one), Aminah taught students Idea C (flotation) and Idea D (immersion) using the same application, a submarine. A submarine applies both ideas. She used the lecture activity and used the representations of VS, WS, P, and RLS. Other representations, namely M, G, T, and F were not evident.

Aminah gave lectures assisted with a picture of a submarine (Figure 7). She explained how the submarine works – increasing the weight of the submarine to make it submerge deeper (Objective 2). Figure 7 illustrates the ballast tanks used by the submarine. Figure 7 shows the submarine application and the use of ballast tanks.

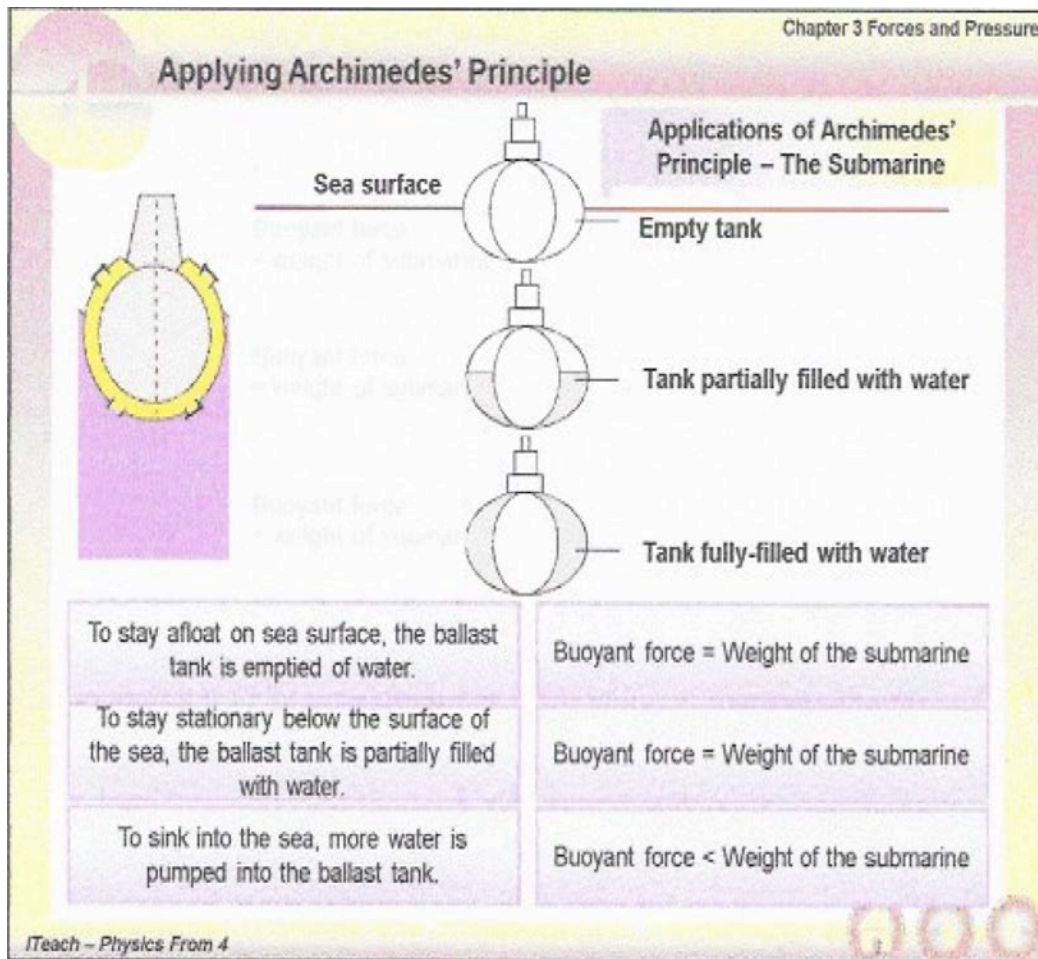


Figure 7. A submarine and ballast tanks.

[Code: AM-DOCSL-July 27-13]

Aminah's lecture was as follows:

For a submarine, on the surface of the sea, to stay afloat, the ballast tank is emptied of water. The ballast tank is filled with seawater. If the ballast tank is filled partially, the buoyant force is equal to the weight of the submarine. For the submarine to submerge deeper, it must have a greater weight. When the ballast tank is completely filled with seawater, the weight of the submarine increases. So, the buoyant force is less than the weight of the submarine. Thus, the weight of the submarine is larger than the buoyant force, so the submarine submerges deeper.

[Code: AM-VOR-July 27-8]

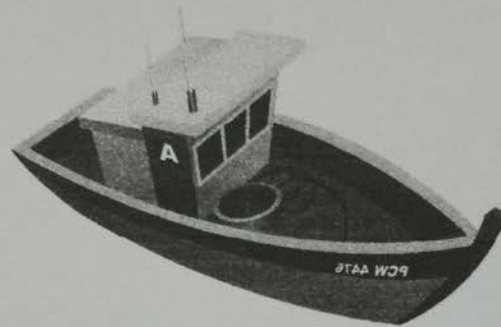
Aminah ended her first lesson on Archimedes' principle. She then taught students Bernoulli's principle in the same lesson. She used notes that she wrote on the whiteboard for teaching this principle. The notes covered the definition of the principle as well as real-world applications of the principle. She gave lectures on the definition of Bernoulli's principle and then applications like Venturi tubes and Bunsen burners. No mathematical formula is involved in Bernoulli's principle. The national curriculum also does not suggest any mathematical formula or calculations for the principle of Bernoulli.

Teaching episode 7: Idea C. On the second lesson, on July 28, 2015, Aminah continued her teaching on Pascal's principle, Archimedes' principle, and Bernoulli's principle in the same lesson. The main activity was small group exam practice. She asked students to work in groups of eight. Aminah used five

qualitative questions and three quantitative questions. All questions came from a commercial book. She picked and photocopied the questions and gave them to students. Each group got one question, and was given either a quantitative or qualitative question on those three principles. She moved from one group to another to guide students to answer those questions. She used the representations of VS, WS, P, and RLS while F, M, G, and T representations were not used.

Aminah was captured talking with students about a qualitative question related to Idea C regarding flotation (Objective 3). Figure 8 shows the question she discussed with a group about designing a boat. The question mimicked the national exam question. It was in Malay and English.

Anda dikehendaki memberi beberapa cadangan tentang bagaimana mereka bentuk bot dalam Rajah 5 untuk menambah daya keapungan dan lebih selamat. Terangkan cadangan anda berdasarkan aspek-aspek berikut:
You are required to give some suggestions on how to design the boat in Diagram 5 as to increase the floating force and safer. Explain the suggestions based on the following aspects:



Rajah 5 / Diagram 5

- i. Bahan yang digunakan / *Material used*
- ii. Bentuk bot / *Shape of boat*
- iii. Ketumpatan bot / *Density of boat*
- iv. Komponen tambahan / *Additional components*
- v. Ciri keselamatan / *Safety feature*

Figure 8. Designing a boat.

[Codes: AM-DOCM-July 28-2 & AM-DOCM-July 28-4]

The question in Figure 8 asked students to design a safer boat that would have a greater buoyant force. The question gave some important factors for designing a more secure boat. The factors included: appropriate materials to use to make the boat, the suitable shape for the boat, the density of the boat, extra components to support the boat for floating, and safety measures for using the boat.

One of Aminah's students from a group asked her about the question in Figure 8. The student specifically inquired as to additional components that could be used to add to the magnitude of the buoyant force and safety features. Aminah made conversation with the group's members.

Student₁: Teacher, what are the extra components to use?

Aminah: Design a boat that has a greater buoyant force and is safer. You may use extra components like life buoys. They can add more buoyant force and make the boat safer. Regarding the safety features, you may use two objects, life buoys and life jackets.

[Code: AM-VOR-July 28-1]

Aminah specifically suggested that the group use tools like life buoys and life jackets to increase the ability of the boat and passengers to float. The student and his group then came up with answers for the question. Figure 9 shows the group's answer. They used the Malay language to answer the question.

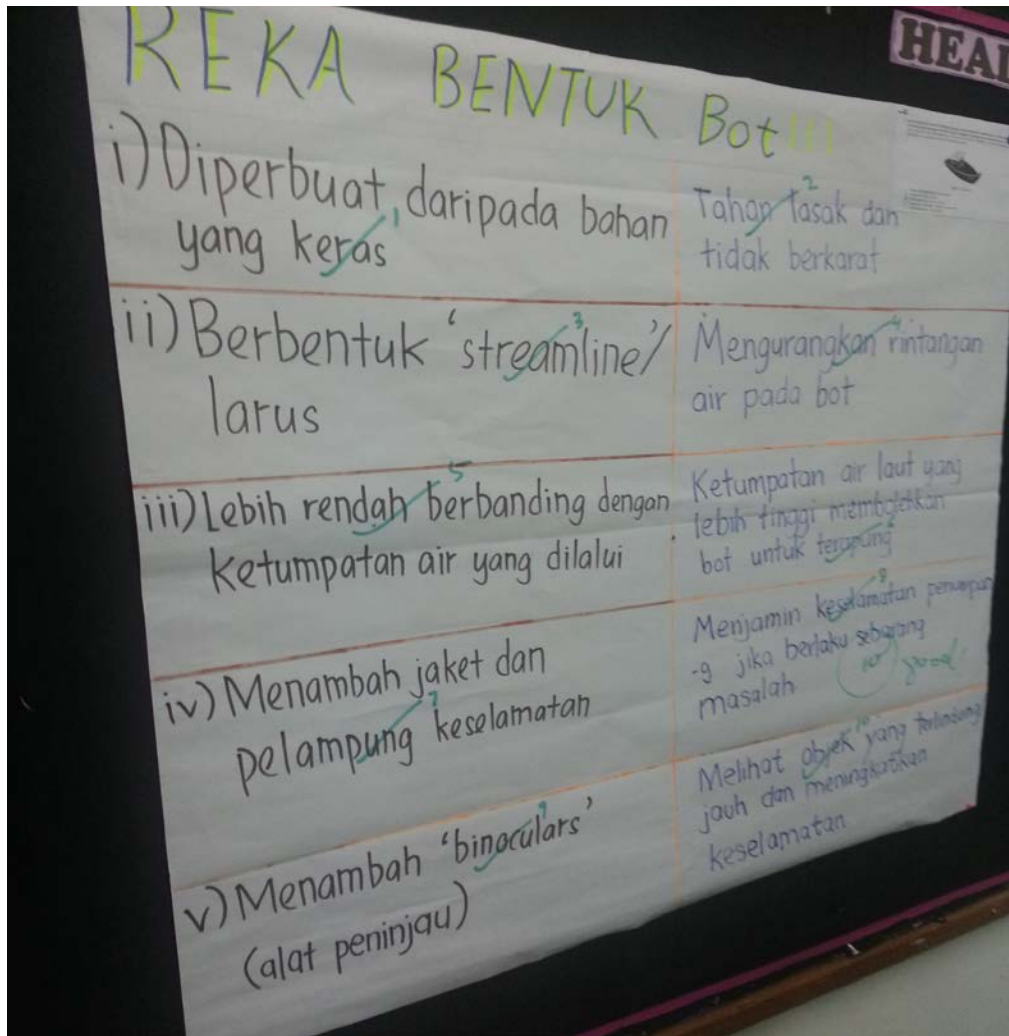


Figure 9. A group's answers.

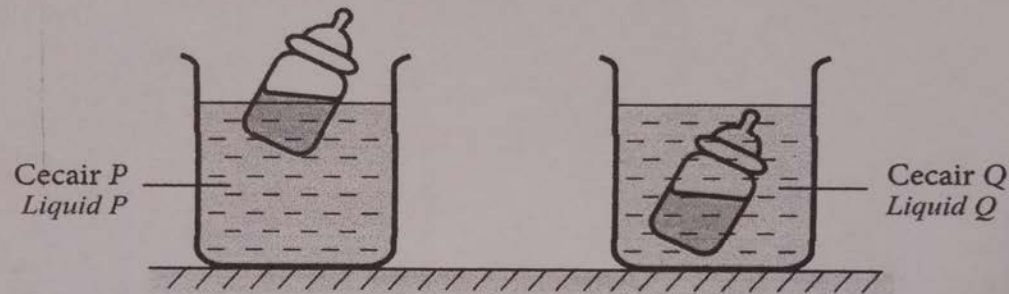
[Code: AM-DOCM-July 28-2 & AM-DOCM-July 28-4]

Figure 9 indicates the responses of a group for the question on making a safer boat. Here are the translations of their work with rephrased translations. The group thought that the boat could be built using materials that are solid and will not be rusted. For its shape, the boat should have a streamlined shape to reduce the water resistance when it is moving on the water. Regarding its density, the group suggested that the density of the boat should be lower than the seawater's

density. For the additional components of the boat, life buoys and life jackets were useful. Regarding the safety features, binoculars could be used to know the current distance of the boat from lands. The group provided correct answers to the question. Part of the group's answer may have come from Aminah, especially when she suggested the use of life jackets and life buoys.

Teaching episode 8: Idea C and Idea D. In the same lesson (lesson two), Aminah guided a group to answer a question regarding the Idea A. She was captured talking with a group about the question in Figure 10 (Objective 3). The question was bilingual. When teaching Idea A, Aminah used the small group exam practice activity. She also used the representations of VS, WS, P, and RLS, while F, M, G, and T representations were not used.

Rajah 1 menunjukkan dua botol susu yang serupa masing-masing terapung dalam cecair P dan cecair Q. Botol susu itu terapung kerana daya bersih yang bertindak ke atas botol itu adalah sifar.
Diagram 1 shows two identical feeding bottles floating in liquid P and liquid Q respectively. The feeding bottle floats because the net force acting on the bottle is zero.



Rajah 1
Diagram 1

Menggunakan Rajah 1, bandingkan kedudukan botol susu dalam cecair P dan cecair Q.
Bandingkan juga berat botol dan daya keapungan yang bertindak ke atas botol dalam cecair P dan cecair Q.
Bandingkan ketumpatan cecair P dan cecair Q.
Hubung kaitkan kedudukan botol susu dengan ketumpatan cecair untuk mendeduksikan satu konsep fizik berkaitan.

*Using Diagram 1, compare the position of the bottles in liquid P and liquid Q.
Compare also the weights and the buoyant forces that are acting on the bottles in liquid P and liquid Q.
Compare the density of liquid P and liquid Q.
Relate the position of the bottle and the density of liquid to deduce a relevant physics concept.*

Figure 10. The weight of liquid displaced.

The question in Figure 10 asked students to compare the position of the identical bottles in liquid P and Q. The question wanted students to compare the weight and the buoyant force acting on those bottles and compare the density of liquids of the bottles. Finally, the question asked students to relate the positions of those bottles with the density of the liquids. Aminah was guiding a group to answer the question in Figure 10. For example, she guided one group as follows:

Student₁: Teacher, what about this question?

Aminah: The weight of the bottle. If an object floats, like this, the bottle's weight is equal to the buoyant force. That's why it can float (in liquid P). If it sinks, its weight is greater than the buoyant force. We can't say the magnitude of the buoyant force and the weight of the bottle are the same in an immersion case. Your answers were wrong. The bottle's weight is equal to the buoyant force in the first case (liquid P). For the second case, its weight is greater than the buoyant force.

[Code: AM-VOR-July 28-3]

Figure 11 shows the group's answers. The answers were in English.

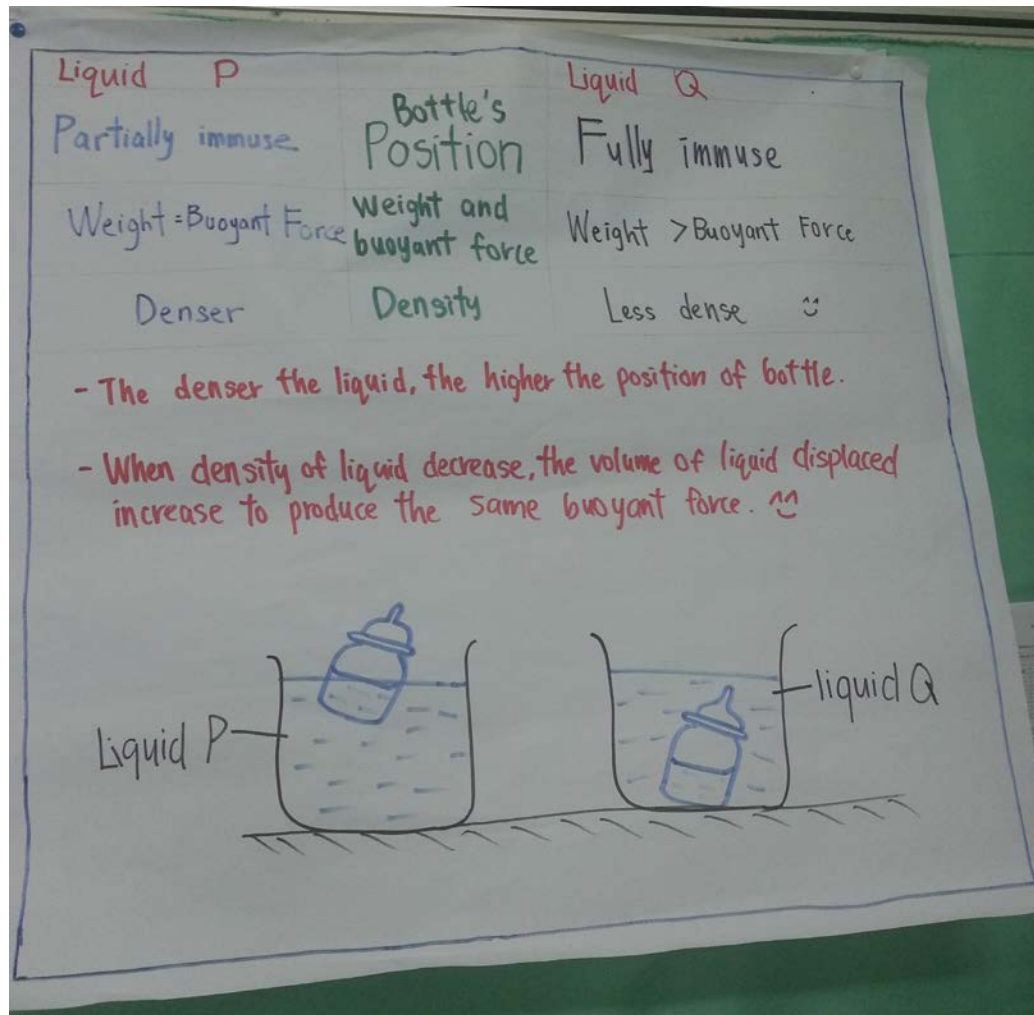


Figure 11. A group's answers to the question regarding the weight of liquid displaced.

Teaching episode 9: Idea C. In the same lesson (lesson two), Aminah guided a group to answer a quantitative problem (Objective 2 and Objective 3). When teaching Idea C, Aminah used the small group exam practice activity. She also used the representations of VS, WS, P, F, and RLS, while G, T, and M representations were not evident. The question is in Figure 12.

4 Rajah 4 menunjukkan belon yang mengandungi helium. Isi padu belon itu ialah 1.0 m^3 . Ketumpatan gas helium ialah 0.17 kg m^{-3} . / Diagram 4 shows a balloon which contains helium. The volume of the balloon is 1.0 m^3 . Density of helium gas is 0.17 kg m^{-3} .



Rajah 4 / Diagram 4

- a. Dengan mengabaikan jisim belon, hitungkan jisim gas helium dalam belon itu.
By ignoring the mass of the balloon, calculate the mass of helium gas in the balloon.

- b. Hitungkan daya keapungan yang bertindak pada belon itu. [ketumpatan udara ialah 1.3 kg m^{-3}]
Calculate the buoyant force which acts on the balloon. [density of air is 1.3 kg m^{-3}]

Figure 12. A quantitative question about the application of Idea C, a hot air balloon.

The question in Figure 12 asked the group to find the mass of helium gas in a balloon and the buoyant force exerted on the balloon. A group member asked Aminah about their answers.

Student₁: Teacher, are these answers correct?

Aminah: 3(a) is 30 000 N. The answer for 3(b) is 20 000 N. The answer for 4 (a) is 0.17 kg and 4 (b) is 13 N.

Student₁: OK.

The group showed Aminah the answers for the question in Figure 12. Aminah checked their answers and found that those were correct. This happened during the small group work activity. Figure 13 shows the group's answers.

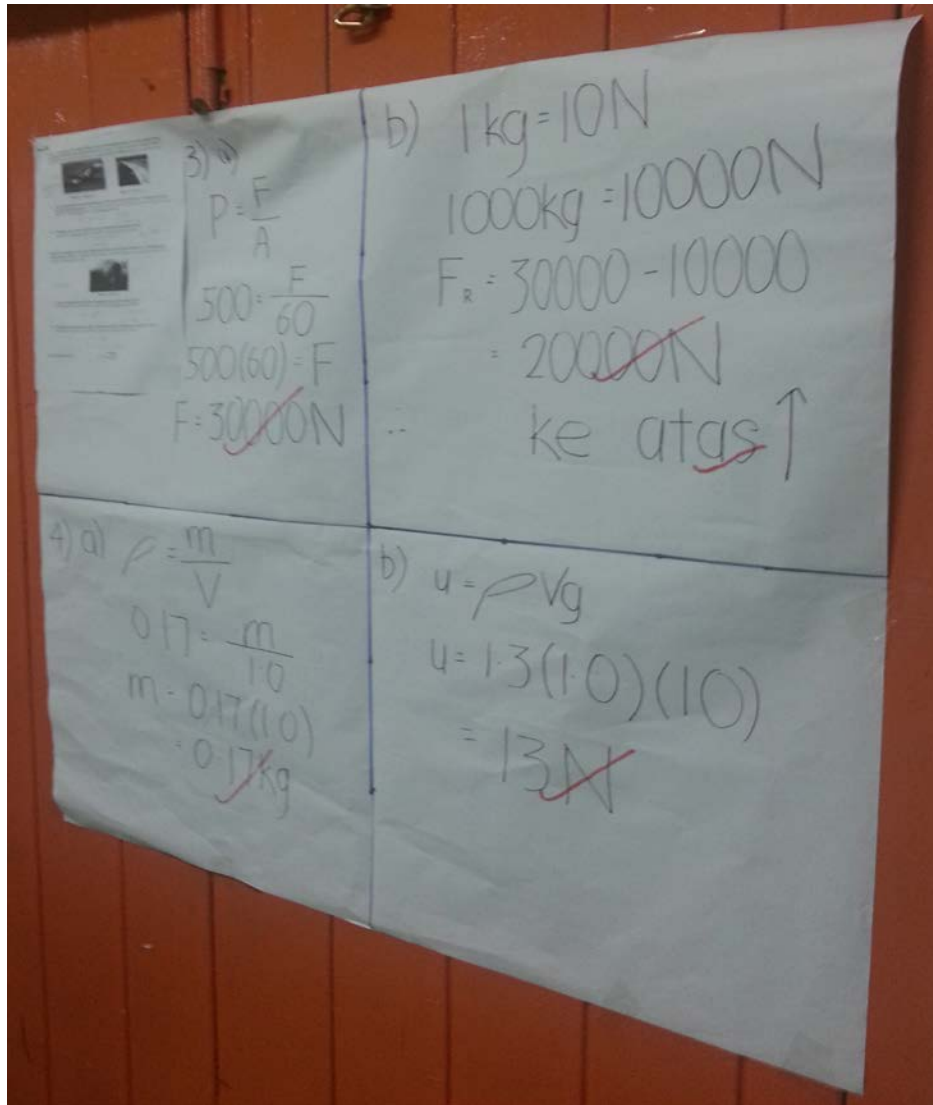


Figure 13. The group's answer to the quantitative problem on flotation (4 (a) and (b)).

Aminah confirmed that the group produced right answers for the question in Figure 13. They found the mass by multiplying the volume of the balloon, 1.0 m^3 and the density of the helium gas, 0.17 kg m^{-3} . They got the mass of the balloon 0.17 kg . The group also gave a correct answer for 4 (b) where they applied the formula of $F_B = \rho Vg$, which is the formula of Archimedes' principle.

Knowing that the density of air is 1.3 kg m^{-3} , the volume is 1.0 m^3 , and the gravitational acceleration is 10 m s^{-2} , they got the answer of 13 N. It was the idea of flotation where the buoyant force exerted on the balloon is equal to the weight of the balloon.

Teaching episode 10: Idea D. In the same lesson (lesson two), Aminah guided a group to answer a question regarding the Idea D (Objective 3). Figure 14 shows the question regarding immersion. A submarine applies the immersion idea.

Anda diminta menyiasat ciri-ciri bagi empat kapal selam dalam Jadual 4.

You are required to investigate the characteristics of four submarines shown in Table 4.

Kapal selam <i>Submarine</i>	Isi padu tangki ballast <i>Volume of ballast tank</i>	Bilangan tangki udara <i>Number of air tank</i>	Tekanan maksimum yang boleh ditahan <i>Maximum pressure to be tolerated</i>	Bentuk kapal selam <i>Shape of submarine</i>
P	3 000 <i>l</i>	15	4.5 atm	Segi empat <i>Rectangular</i>
Q	2 500 <i>l</i>	30	6.0 atm	Larus <i>Streamline</i>
R	350 <i>l</i>	3	6.1 atm	Larus <i>Streamline</i>
S	400 <i>l</i>	1	2.0 atm	Pentagon <i>Pentagon</i>

Jadual 4 / *Table 4*

Terangkan kesesuaian setiap ciri kapal selam dan tentukan kapal selam yang boleh bergerak laju, berada lebih lama di dalam air laut yang lebih dalam dan boleh membawa lebih banyak anak kapal. Beri sebab bagi pilihan anda. / *Explain the suitability of each characteristic of the submarines and determine the submarine which can travel faster, stay longer in deeper sea water and able to carry more crews. Give reasons for your choice.*

Figure 14. A question about designing a submarine.

Figure 14 shows a question regarding immersion, the Idea D. The question asked the group to choose a submarine that is the most suitable for using in a deep sea. The requirements are: (a) it can move faster, (b) it should stay longer in a deeper ocean, and (c) it should be able to bring more crewmembers. The group needed to understand that a well-designed submarine should have more volume of ballast tanks. A greater volume of ballast tanks can hold a larger amount of seawater to allow the submarine to submerge deeper. She had already taught students the application of submarines in teaching episode 6 regarding Idea D. The shape should be a streamlined structure to make the submarine move faster. The group needed to apply Bernoulli's principle in order to answer the shape question. Aminah taught Bernoulli's principle in the teaching episode 6. A dialogue between Aminah and the group was captured:

Aminah: OK. The question about four characteristics of a submarine. What about the ballast tanks' volume?

Student₁: Many.

Aminah: High volume, not many volume. The volume of the ballast tank is high. OK. Don't use the word "deeper" seawater. Please change the word. I don't want this answer. Change it.

Student₂: What about using the word "sink further"?

Aminah: Yes, that's it. To enable the submarine sinks further. Please change the word "deeper." Please, don't repeat the sentences used in the question.

[Code: AM-VOR-July 28-2]

When facilitating the group's problem solving, she guided the group to answer the questions by checking students' tentative answers. She reminded the group to use accurate terms like "high volume" instead of "many volume." Besides, she asked them not to repeat sentences used in the question. For instance, the question in Figure 14 used the word "stay longer in deeper seawater." Aminah did not want the group to use the same words or sentences so she asked the group to rephrase the wording. A group member suggested the use of word "sink further," and Aminah accepted the proposed words. Figure 15 shows the group's answer.

Submarine

Characteristic	Reason
Volume of ballast tank	<ul style="list-style-type: none"> - Increase the volume of water in ballast tank. - Can bring the submarine sink further in the sea.
Number of air tank $\rightarrow \uparrow$ increase	- Increase the amount of \checkmark to supply the crew air
Maximum pressure to be tolerated \uparrow increase	- Enable for the submarine to sink further
Shape of submarine (streamline)	- Reduce the resistance of water.

I choose Submarine $\rightarrow \uparrow$ \odot \odot

Figure 15. The group's answers of the submarine application.

The group chose submarine Q. Their answer was correct. Even though the submarine Q (Figure 14) has a lower amount of volume of ballast tanks than submarine P, submarine Q has a streamlined shape that can help it move faster in a deep ocean. The rectangular shape of submarine P makes it hard to travel smoothly. The idea of an appropriate shape for a submarine is related to Bernoulli's principle. A streamlined shape can allow a submarine has a lower water resistance.

When teaching Idea D, Aminah used the small group exam practice activity. She also used the representations of VS, WS, and RLS, but did not use P, F, M, G, and T representations.

Teaching episode 11: Final episode. In the same lesson (lesson two), Aminah lectured to the whole class about the questions on submarines (Figure 14), a boat (Figure 8), and bottles in two different liquids (Figure 10). The submarine was related to the Idea D regarding immersion, the boat was connected to Idea C about flotation, and the bottles were related to Idea A regarding the weight of liquid displaced. The representations used were VS, WS, and RLS, but other representations of M, P, F, G, and T were not used.

In this teaching episode 11, Aminah mainly lectured the whole class about how to answer those three questions regarding Archimedes' principle (Objective 3). Those questions were qualitative problems. In this episode, Aminah lectured to students on the qualitative type of questions. No quantitative questions were discussed with the class. In addition, no group presentations were required.

Before starting this episode, Aminah first praised the class for good cooperation among group members. She said to the class:

Thank you for your cooperation. Please give yourselves a hand
(students clapped).

[Code: AM-VOR-July 28-1 & AM-VOR-July 28-6]

Aminah then reminded students to pay attention to the tips given for answering those questions because they mimicked the national exam question. For example, she told students how to respond to the question on the submarines (Figure 14).

See the question. Explain the suitability of each characteristic of the submarines and determine which submarine can travel faster, stay longer in deeper seawater, and carry more crews. There are a lot of keywords. First, it can travel faster. Second, it should stay longer in deeper seawater. Third, it should be able to carry more crews. Don't use these keywords in your answers. OK. The volume of the ballast tanks must be large. Why? They can make the submarine stay longer in deeper seawater. However, you must change the word "deeper seawater." You may change to a new word like "further underwater." These are the tips for answering exam questions. If you repeat the exact words used in the question, you are considered not to have responded to the question. You should not do that.

[Code: AM-VOR-July 28-11]

Aminah used this final episode (episode 11) for teaching students how to answer exam questions because the questions she provided to students mimicked national exam questions. The tips she gave to students were for the qualitative type of questions. She reminded students not to repeat keywords used in a question because if they do that, they are deemed not to have answered the question.

Main characteristics of Aminah's teaching activities. Based on the whole teaching episodes, Aminah utilized three teaching activities: (1) small group exam practice, (2) lectures, and (3) questioning during whole class lectures. Other activities like demonstrations, lab work, and building physical models were not evident.

Small group exam practice. Aminah conducted this activity to:

- (1) Help students answer questions based on the national exam requirements.

She gave students a set of questions that mimicked the national exam questions (episodes 7, 8, 9, and 10).

- (2) Help students answer questions scientifically correctly. She confirmed the groups' answers when they were correct and made right ticks on the groups' answers on the posters (episode 9).

- (3) Correct students' answers when they were wrong. She corrected the groups' answers when they were wrong by explaining the right answers and the right techniques to answer a question, and asked the groups to change their answers (episode 8, 10).

(4) Suggest to students some answers when students asked questions to the teacher. She provided ideas for answering questions by suggesting several important points to the groups and the groups used the teacher's ideas (episode 7).

This activity was somewhat student-centered because the students worked in groups to find relevant answers to the questions given while the teacher helped the groups when they needed help from the teacher.

Lectures. Aminah adopted this activity to:

(1) Explicate concepts, formulae, and applications of Archimedes' principle extensively – rarely briefly. Aminah briefly lectured about Idea A, about the concept of the weight of liquid displaced that is equal to the buoyant force (episode 2). She then gave an extensive lecture on Idea B, about the concept of the loss of weight of an object immersed in a liquid (episode 3). Next, she went back to lecturing about Idea A by explaining the formula of $F = V\rho g$ (episode 4) in-depth. She also lectured about applications of Archimedes' principle when explaining Idea A in episode 4. After that, she lectured at length about Idea C regarding flotation, and combined Idea C with Idea A to discuss the weight of liquid displaced specifically through the application of Plimsoll lines by ships in episode 5. Later, she gave in-depth lectures on Idea C and Idea D by explaining the application of submarines.

(2) Teach students the right techniques to answer questions based on the national exam requirements. Aminah gave a long explanation on the right techniques to answer questions according to the requirements of the national exam in the final episode, episode 11. One important point was for students to remember not to use terms that were already used in a question when answering it.

The lecturing activity was completely teacher-centered because Aminah explained the concepts, formulae, applications, and the techniques for answering national exam questions without interactions with the students.

Questioning during whole class lecture. This activity was used to ask students questions about Archimedes, the founder of Archimedes' principle. Aminah asked students a question about the foundation of Archimedes' principle in episode 2. Her student responded to her question by exclaiming, "Ooo!" which showed that students might know about Archimedes. Aminah continued to explain that Archimedes entered a bathtub, and she again asked students a question about the situation. One student said that some amount of water spilled out of the bathtub. Aminah finally explained that this incident from Archimedes' life inspired him to articulate what is now known as Archimedes' principle after Archimedes discovered that the total weight of water displaced was equal to the buoyant force exerted by his body.

The questioning activities were mainly teacher-centered because the teacher initiated questions, then students gave answers, and the teacher gave

feedback to students' responses. An IRF pattern was evident: *Initiation* (teacher posing questions), *Response* (students providing answers), and *Feedback* (teacher giving reactions to students' responses). The teacher primarily led the dialogue with students.

Main characteristics of Aminah's translation of representations in selected episodes. This section is about translation of representations that Aminah used in teaching episodes about Idea A and the associated ideas. Episodes about Idea A and the associated ideas were selected because Idea A is the most general statement of Archimedes' principle and because Idea A was often related to other ideas. In Aminah's case, episodes 2, 4, and 5 were selected because of these reasons.

Key symbols were used, with these meanings: M = manipulative, VS = verbal symbols, WS = written symbols, P = pictures, F = formulae, RLS = real-life situations, subscripts of _s = student-generated representations, subscripts of ₁₋₉ = the sequence of using particular representations, subscripts of _{a-d} = representations from different sources, and arrows \rightarrow = translations across and within modes of representations.

In episode 2, Aminah translated modes of representations in this manner: $WS_{a1} \rightarrow VS_{a1} \rightarrow RLS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1}$. This translation of her sequencing is read as:

From written notes about all four ideas that were written in front of the class, Aminah verbally explained about Archimedes' principle

($WS_{a1} \rightarrow VS_{a1}$). Then she gave as an example a story of Archimedes' swimming and displacing water as a real-life situation and then moved to using dialogues with students about the foundation of Archimedes principle ($RLS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1}$). Thus, the complete sequence of translations in this episode was $WS_{a1} \rightarrow VS_{a1} \rightarrow RLS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1}$.

The modes involved were WS, VS, and RLS. Other modes of representations were not evident, namely G, T, P, M, and F.

In episode 4, the sequence of translation was: $WS_{a1} \rightarrow F_{a1} \rightarrow VS_{a1} \rightarrow F_{a2} \rightarrow RLS_{a1} \rightarrow VS_{a2} \rightarrow P_{a1} \rightarrow VS_{a3}$. This translation is read as:

Aminah used the notes that she wrote on the whiteboard regarding the formula of Archimedes' principle, $F = pVg$ and then gave lectures that explained the formula ($WS_{a1} \rightarrow F_{a1} \rightarrow VS_{a1}$). She then used the same formula to explain its applications in real-life situations like hot air balloons and submarines ($F_{a2} \rightarrow RLS_{a1} \rightarrow VS_{a2}$) and she sketched an object that was partially immersed in a liquid and explained that students just need to consider the immersed part of the object to calculate the magnitude of the buoyant force ($P_{a1} \rightarrow VS_{a3}$). Thus, the complete sequence of translations in this episode was $WS_{a1} \rightarrow F_{a1} \rightarrow VS_{a1} \rightarrow F_{a2} \rightarrow RLS_{a1} \rightarrow VS_{a2} \rightarrow P_{a1} \rightarrow VS_{a3}$.

Based on this translation, the modes involved were WS, F, VS, RLS, and P. Other modes, G, T, and M, were not evident.

In episode 5, Aminah used this sequence of translation: $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1} \rightarrow VS_{a3} \rightarrow RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a4}$. This translation is read as:

From a slide that shows the picture and written explanations of the application of a ship, Aminah gave in-depth lectures about that real-life application, particularly in explaining Idea C about flotation ($RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1}$). Using the same slide that also contained another application, Plimsoll lines on a ship, she explained the application of Idea A ($RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a2}$). Then, one of her students asked question of how to measure density of seawater, and Aminah replied that a hydrometer could be used ($VS_{s1} \rightarrow VS_{a3}$). She further explained the use of hydrometer using a slide that shows a picture of a hydrometer and written explanations of that real-life application ($RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a4}$). Overall, this translation was $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1} \rightarrow VS_{a3} \rightarrow RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a4}$.

This translation involved RLS, P, WS, and VS modes. Other modes, F, M, G, and T were not apparent.

Overall, Aminah's uses of representations indicate that verbal symbols (VS) and written symbols (WS) surrounded real-life situation (RLS) and formula (F) representations in the selected episodes. VS primarily came from lectures while WS came from written materials. RLS and F representations were mainly portrayed through pictures (P), VS, and WS. Nonetheless, representations of tables (T), graphs (G), and manipulatives (M) were not used in any episodes.

Amplifiers and filters. This section describes Aminah's amplifiers and filters of teaching that included instructional goals, reasons for adopting particular teaching activities, and contextual and/or personal factors that shaped her instruction.

Contextual amplifiers. There were two kinds of contextual amplifiers: (1) national contextual amplifiers and (2) school contextual amplifiers. The first national contextual amplifier was the requirement to finish teaching the national syllabus. Completing the syllabus was important because every student would be assessed on each physics topic covered in the national curriculum when taking the national examination at the end of the year 2016. Hence, finishing the syllabus was a must for Aminah. She said that:

As a teacher, it is necessary to finish teaching the syllabus provided in the national curriculum of physics by the Ministry of Education. I will do my very best to carry out this challenging task because there are many challenges like time constraints and assessment.

[Codes: AM-PREIN-June 23-5, AM-PREIN-June 23-22, & AM-
POSTIN1-Aug 18-7]

The second national contextual amplifier was the recommendation of a particular order for teaching physics topics set forth by the national curriculum, and instructional objectives. Before Aminah taught Archimedes' principle, she had finished teaching the topics of pressure, pressure in liquids, atmospheric pressure and gas pressure, and Pascal's principle as was recommended. The reason she followed this sequence was that the national curriculum had given this as a logical order in sequencing fundamental and advanced topics. Aminah said that basic physics concepts like pressure and pressure in liquids were necessary to teach before teaching a sophisticated concept like the Archimedes' principle. This organization set by the national curriculum helped her teach in an appropriate order [Code: AM-POSTIN1-Aug 18-11]. Aminah also adopted instructional objectives of Archimedes' principle given in the national curriculum.

The third national contextual amplifier was the recommendation on teaching activities for teaching Archimedes' principle. The national curriculum suggests teachers to use inquiry-based learning, specifically lab works, discussions, and models. Aminah adopted the discussion activity, but did not adopt the lab work and building physical models [AM-POSTIN1-Aug 18-8, AM-POSTIN1-Aug 18-9, & AM-POSTIN1-Aug 18-10].

The fourth amplifier was both, a national and school contextual amplifier, which was to prepare students for taking the national exam and school exams.

School exams followed the format of the national exam questions. She said that:

When I was teaching, my focus was not just on applications of physics in the real world. I also concentrated on the past questions of the national exam, especially questions of high-order levels.

[Code: AM-POSTIN1-Aug 18-18]

Aminah's goal was not just to educate students about applications of physics in the real world. She thought she also should prepare students for taking the national and school exams. Aminah recognized that preparing students for exams and tests was important because the current assessment practice employed in Malaysia for high school (upper secondary education) is still examination-oriented. She mentioned that:

I notice that the current assessment practice at the national level now is still examination-oriented through a paper-based assessment. I mean *Sijil Pelajaran Malaysia (SPM)* (Malaysia Certificate of Education – MCE). So, I need to balance the goals of teaching students for understanding applications in the real world and teaching students for examination preparation. What I usually do is to complete teaching applications first, and then I give questions that mimic the national examination's format and style later.

[Code: AM-POSTIN1-Aug 18-19]

Other contextual amplifiers were Aminah's school status, target for academic achievement, and scoring well on school exams. These are school amplifiers. She revealed that her school is one of the top schools in the district. She said that her school placed a high priority on academic achievements:

My school is one of the best schools in this district. We are placed in the fourth or fifth rank in this district. My school puts a high target for students' academic excellence, specifically on helping students get the grades A+ and A. This goal is set based on the consensus among physics teachers in this school. We put the target differently every year because we get different types of students. We agreed that we should adhere to the goal of the school.

[Code: AM-PREIN-June 23-27]

Contextual filters. One contextual filter was insufficient laboratory supplies. This was a school filter. Aminah actually planned to adopt the laboratory work activity for teaching ideas of Archimedes' principle. She said that:

A laboratory work activity is suitable for teaching Archimedes' principle because we cannot see the principle concretely. For instance, the buoyant force. Does the buoyant force exist? Some students may not realize the existence of the buoyant force. If we do a laboratory work, students can investigate the existence of the force by measuring the weight of an object in air and a liquid. They

can see the difference in weights. The lab work activity can make students better understand buoyant force.

[Code: AM-POSTIN2-Aug 22-30]

Nonetheless, due to the problem of defective lab equipment for investigating Archimedes' principle, she used the lecture activity in teaching episodes 2 to 6.

She mentioned that:

The problem now is insufficient lab equipment. Many of the apparatuses were outdated and rusted. Students may just be able to see those tools but cannot use them. What I did was, I captured a picture and put it on the slide of teaching to make students be able to see the investigation via a visual image. For example, they can see Eureka tins used in the investigation of Archimedes' principle. I did that to help students see the methods of investigation. I believe that students can learn better through the use of pictures and not just verbal symbols.

[Code: AM-POSTIN2-Aug 22-31, AM-POSTIN2-Aug 22-32, AM-POSTIN2-Aug 22-33, AM-POSTIN2-Aug 22-34, & AM-POSTIN2-Aug 22-35]

Time constraints were also another contextual filter. This was a school filter. Aminah mentioned that:

I thought that time availability or flexibility is an important factor of teaching. I felt that the current allocation of time for teaching

physics is limited. I needed to transmit knowledge, run discussions, and complete other activities in a relatively short time, around one hour. The instructional time was so tight. We may one day need to adopt the university's timetable like just having two or three subjects in a day. We may need to give 2 hours or 2.5 hours to the physics subject including doing laboratory tasks. This is important for students to have more opportunities and time for applying their knowledge of physics.

[Code: AM-POSTIN2-Aug 22-79]

Personal amplifiers. Aminah's personal instructional goal was to engage students with real-world applications of physics because physics has a close connection with students' lives. She believed that her students always saw natural phenomena and applications in daily living that could be explained using physics knowledge. Aminah stated that:

Personally, my goal of teaching physics is to educate students to practice science in their lives, not just learn through books. Physics is the mother of all types of science. It means physics is the closest science to humans. Each phenomenon that happens in real lives can be connected and explained by science concepts. I use the tagline of "Learning Physics for Life." This slogan means we learn not for exams, but life. For instance, students go swimming. They

might be curious about why a heavy person can float on water. The concept of buoyancy is so close to students' lives.

[Code: AM-POSTIN1-Aug 18-3, AM-POSTIN1-Aug 18-25, AM-PREIN-June 23-1, AM-PREIN-June 23-2, & AM-PREIN-June 23-3]

Aminah taught students about applications of Archimedes' principle like submarines, ships, hot air balloons, and hydrometer, especially in episodes 5, 6, 7, 9, and 10.

Aminah also indicated that she wanted to teach students to apply physics in their lives rather than for taking exams. In fact, she wanted the assessment system to be more flexible and not totally exam-oriented. She said that:

When the government still wants the exam-oriented system of assessment, it somehow affects teaching. I attempt to make students understand real-world applications. However, due to the assessment constraints, I need to cut part of my content and stay limited to just what students need to know for exams. I disagree that examinations ought to be removed entirely from the assessment system. However, I thought that the national assessment should be more lenient, and we educators should not just make students perform excellently in exams. For now, I need to balance the goals of preparing students for exams and my

personal goal of teaching students for understanding real world applications.

[Code: AM-PREIN-June 23-33]

During episode 11, Aminah specifically taught students how to answer questions based on the national exam requirements. In the previous episodes, she asked students to work in groups to solve problems that involved real-world applications of Archimedes' principle.

The following paragraphs are about Aminah's reasons for using particular teaching activities.

Small group exam practice. Aminah implemented this activity when teaching students in teaching episodes 7 to 10. During those episodes, she asked students to work in groups of eight, and each group got either a quantitative or qualitative question (see Figure 12, Figure 8, Figure 10, and Figure 14). She guided student groups by checking groups' answers or suggesting ideas when students asked her. For example, while she was teaching episode 7, a group member asked her about additional components for a boat. Aminah suggested they use life buoys and life jackets. Another example was in teaching episode 9 where the group members asked Aminah to check their answers regarding the quantitative question on hot air balloons. She verified the group's answers, and they provided accurate answers to the question.

During the interviews, Aminah provided some reasons for using the small group exam practice activity. The first reason was to encourage collaboration among group members. She stated that:

The reasons I did the small group exam practice activity was first to make students collaborate with each other. I can make them do it individually, but this did not seem appropriate given the time constraints. If I used a large group work activity, the scope of discussion would be larger among students. So, I created small groups instead of big groups. I saw that students were eager to get involved in solving those questions in groups. They had good cooperation among group members. If a student needed to modify an object like a car, he or she could not do it alone. They needed to work together in teams, which can modify a product better than individuals can work alone.

[Code: AM-POSTIN2-Aug 22-22 & AM-POSTIN2-Aug 22-23]

In the teaching episode 11, Aminah indeed honored her students' cooperation. The whole class clapped their hands to show appreciation to group members. The analogy of designing a car could be a reflection of the use of questions of designing a boat and a submarine in the teaching episode 7 and 10.

The second reason was to prepare students for answering the national exam questions. Aminah mentioned that:

The second purpose was regarding the demands of the national examination. For past several years, I was an examiner for the national exam. So, I have seen the demands of the national exam. The national exam wants students to be able to apply several principles for answering a single question. It requires students to combine knowledge of either Pascal's principle and Archimedes' principle or Archimedes' principle and Bernoulli's principle. When I combine those principles together in a single question, students can get the idea of how to use multiple ideas on those principles to answer questions. Those types of questions (involving a combination of several principles) have a big mark, ten marks.

[Code: AM-POSTIN2-Aug 22-36 & AM-POSTIN2-Aug 22-37]

Aminah indeed provided students with questions that required them to put together understandings of two principles – Archimedes' principle and Bernoulli's principle. These questions were evident in the teaching episode 7 (designing a boat – Figure 8) and episode 10 (designing a submarine – Figure 14). The question in the teaching episode 10 demanded students to apply the idea of the volume of ballast tanks of a submarine (the Archimedes' principle) and the shape of the submarine (the Bernoulli's principle). The question in the teaching episode 7 also required students to apply ideas on those two principles, specifically the density of the boat (Archimedes' principle) and the shape of the boat (Bernoulli's principle).

It was evident that Aminah's use of those questions on Archimedes' principle and Bernoulli's principle was to prepare students for the national exam. During the teaching episode 11, the final episode, she taught students how to answer qualitative questions. She reminded students not to repeat keywords used in a question when answering the question because students are deemed not to have answered the question if they do that.

The third reason was regarding Aminah's personal beliefs about assessment. As already mentioned, she wished the national assessment practice to be more lenient, and she taught students for applying physics knowledge in the real world and not just for taking exams. She provided students with application-type questions in the teaching episode 7 to 10, like designing a boat and a submarine. Those questions imitated the national exam questions and also allowed students to understand the applications of the boat and submarine in the real world settings. She encouraged collaboration among students and also gave an analogy of collaboration, designing a car in a group (see the quote of AM-POSTIN2-Aug 22-36 and AM-POSTIN2-Aug 22-37). However, it is known that the national exam assesses students individually, not in groups. The use of the activity could be consistent with Aminah's personal instructional goal, teaching physics to apply physics in their lives rather than for taking exams.

Lectures. Aminah used this activity in the teaching episodes 2 to 6 and episode 11. During those episodes, she lectured about Idea A, Idea B, Idea C, and

Idea D (episode 2-6) and keywords of Archimedes' principle for answering exam questions (episode 11).

The first reason for using the lectures was to make students know keywords of Archimedes' principle that are essential for answering examination questions. Aminah said that:

Students needed to know some keywords in answering examination questions. If they do not state those keywords in their answers, they will get no marks. I wanted to familiarize students to use those keywords.

[Code: AM-POSTIN2-Aug 22-9 & AM-POSTIN2-Aug 22-10]

Aminah indeed stressed the use of right keywords for answering examination questions. In the teaching episode 11, she used the final episode of teaching for lecturing students how to use correct keywords. For instance, students were reminded that they cannot repeat keywords used in a given question. They must rephrase their answers because by using the same keywords from the question, students are considered not to have responded to the question.

The second reason was the issue of laboratory supplies. Aminah actually intended to use the laboratory work activity for teaching ideas of Archimedes' principle but she changed her mind due to the shortage of lab supplies. This issue is explained in-depth in the section of "contextual filters."

Questioning during whole class lectures. Aminah used this activity when teaching Idea A regarding the weight of liquid displaced and the buoyant force in

the teaching episode 2. Aminah stated that students' prior knowledge in Archimedes' principle were central to making them understand the principle in real-world settings. She said that:

I wanted students to share their experience on Archimedes' principle. Students' prior knowledge or experience can help them learn better. They help students imagine and feel applications of the principle in daily activities.

[Code: AM-POSTIN1-Aug 18-27 & AM-POSTIN1-Aug 18-59]

Her verbal question to students about Archimedes – who is the founder of the principle – was to capture students' existing knowledge about the history of the principle of Archimedes. The dialogue between Aminah and one student showed that he already knew that some amount of water volume was moved from the bathtub when Archimedes entered the pool instantly. From that response, she enriched students' existing knowledge about the Archimedes story by explaining the existence of the buoyant force. Nonetheless, Aminah did not spend much time using this activity.

Personal filters. One personal filter came from Aminah's decision to use certain curricular materials like slides and the selected commercial book for her teaching. She used the slides and the book purchased from commercial companies that led her to rely on these materials. Hence, these curricular materials informed the content of her teaching and directed her instruction in certain ways. For example, she used the written questions from a company's book when conducting

small group exam practice activities. She may use other questions from other sources but she decided to use the questions from the purchased book.

Case II: Aishah

Aishah's background. Aishah earned a bachelor's degree in physics education in 2010 from a public university in Malaysia. She has been teaching physics for six years at the upper secondary school level (equivalent to grades 11 and 12 in the US). She taught at a suburban school that had a status of a cluster school with students consisting mostly of middle achievers. Her school's location is in Johor, Malaysia. Throughout her service as a physics teacher, she was exposed to professional development programs like inquiry-based science education (IBSE).

Aishah's physics class. Aishah taught physics, which was a compulsory subject for students who were taking the science stream. She usually taught the subject for two 70-minute periods each week based on the timetable given by her school. Aishah primarily used Malay as the language of instruction. However, curricular materials that she used were in dual languages, Malay and English.

When she was teaching Archimedes' principle, she used four lessons in two days (August 17, 2015, and August 24, 2015). During the first lesson (August 17, 2015), she first finished teaching Pascal's principle. She then moved to teaching Archimedes' principle. In the second lesson (August 17, 2015) and third lesson (August 24, 2015), she used the lessons for teaching the Archimedes'

principle only. In the fourth lesson (August 24, 2015), she summarized the lesson on the Archimedes' principle, Pascal's principle, and Bernoulli's principle.

The primary curricular material she used was a commercial book purchased from one company. All of her students had the book. Aishah had the teacher version. The book covered written questions on Form 4 (Grade 11) Physics topics including Archimedes' principle. Those written questions imitated the national exam questions. These curricular materials align with the specifications of the national curriculum. Aishah used the book mainly for discussing written questions with students.

Classroom practices. Aishah set three learning objectives indicating what students should achieve: (1) state the principle, (2) describe applications of the principle, and (3) solve problems regarding the principle. These objectives came from the national curriculum [Code: AI-DOCM-Aug 17-12, AI-DOCM-Aug 24-4, AI-DOCM-Aug 24-5, AI-DOCM-Aug 24-6, AI-DOCM-Aug 24-7, AI-DOCM-Aug 17-16, AI-DOCM-Aug 24-1, & AI-DOCM-Aug 24-2].

Aishah taught Archimedes' principle based on four main ideas. Those ideas were:

Idea A: The weight of the fluid displaced by an object is equal to the buoyant force.

Idea B: The weight loss of an object is equal to the buoyant force.

Idea C: In a flotation case, the weight of an object is equal to the weight of the fluid displaced by the object.

Idea D: In an immersion case, the weight of an object is greater than the buoyant force.

[Code: AI-VOR-Aug 17-11, AI-VOR-Aug 17-26, AI-VOR-Aug 17-40, & AI-VOR-Aug 17-43]

All ideas originated from the national curriculum.

Overall, Aishah adopted four activities for teaching the main ideas of Archimedes' principle: (1) questioning during whole class discussion, (2) laboratory work, (3) small group discussion after lab work, and (4) lectures. In total, Aishah allocated 190 minutes for teaching Archimedes' principle in four lessons. She used 147 minutes for the questioning activity, 33 minutes for the lab work, 8 minutes for the small group discussion after lab work, and 2 minutes for the lectures. Her teaching is described in 16 episodes.

Teaching episode 1: Introduction. In the first lesson on August 17, 2015, Aishah discussed with students the written questions on Pascal's principle. The questions were mainly quantitative problems. Those questions came from a commercial book that she and her students purchased. She had the teacher version while her students had the student version. She spent around 21 minutes for teaching Pascal's principle. She finished teaching that principle and prepared to teach Archimedes' principle. She asked a laboratory assistant to prepare all apparatuses and materials for conducting laboratory work on Archimedes' principle.

Teaching episode 2: Idea B. In the same lesson (lesson one), Aishah moved to teaching Archimedes' principle. She used the activities of laboratory work, small group discussion after lab work, and questioning during whole class discussion. The representations used were: (1) verbal symbols (VS), (2) written symbols (WS), (3) a picture (P), (4) real-life situations (RLS), (5) manipulatives (M), and (6) formulae (F). Other representations, namely graphs (G) and tables (T) were not evident.

She first asked students to work in groups of six for carrying out laboratory work on Archimedes' principle. The aim of the first investigation was to study the relationship between the loss of weight of an object and the buoyant force (Objective 1). Aishah specifically gave verbal instructions to students for doing the investigation, step-by-step.

- (1) Fill beakers with 200 ml water.
- (2) Take a load.
- (3) Use a spring balance in groups for measuring the load's weight.
- (4) Each group reported the readings of the load's weight to Aishah.
- (5) Students put the load hung from the spring balance into beakers filled with 200 ml water.
- (6) Each group reported the new readings of the load's weight when the load was immersed in water.
- (7) Each group determined the difference in readings of the load in air and water.

[Code: AI-VOR-Aug 17-11 & AI-OBS-Aug 17-4]

Figure 16 shows the setup of the first laboratory work.



Figure 16. The investigation on the relationship between a buoyant force and the loss of weight of an object.

[Code: AI-DOCPH-Aug 17-1]

The lab work was to show how an object (load) lost part of its weight when it was immersed in water. Before immersing the load, students first measured the value of the load's weight or its actual weight in air. They were able to get the value through the spring balance as shown in Figure 16. Most of the groups got the magnitude of the actual weight of 2.0 N. Students then immersed the load into the Eureka tin. They observed that the value of the load's weight reduced when it was completely submerged in the water. Some of the groups

reported that they got a new reading of weight of 1.8 N while others got 1.9 N and 1.6 N. The difference between the actual weight and the weight of an object in water is called the loss of weight. Hence, the magnitude of the weight loss was 0.2 N if 2.0 N is deducted with 1.8 N. Students' varying values of the apparent weight (the load's weight in the water) were due to errors.

When each group was reporting their values of the loss of weight, one of Aishah's students asked her, "Teacher, why is the value of the object's weight is different in air and water?" Aishah replied, "Haaa." She did not immediately answer her student's question. She instead moved on to the next activity, which was small group discussion [Code: AI-VOR-Aug 17-13].

When the first lab work was completed, Aishah asked students to continue work in groups. She wanted students to discuss in groups why the load had different magnitudes in air and water. She asked each group to give just a single idea about why the difference in weights can occur. Each group then discussed the phenomenon of the weight loss among group members [Code: AI-VOR-Aug 17-16].

When each group had completed discussing their ideas, Aishah asked students to share their thoughts about the difference of weights by writing their ideas on the whiteboard. A representative of each group came in front to write their ideas. Six representatives wrote their ideas. Those ideas were written representations, as follows:

View 1: Pressure in water is different from pressure in air.

View 2: The pressure in air is greater than the pressure in water.

View 3: There is a buoyant force in water.

View 4: The buoyant force in water acts on the object's weight.

View 5: The buoyant force in water affects the weight of the object.

View 6: The buoyant force in water influences the weight of the object.

[Code: AI-OBS-Aug 17-6]

Aishah discussed with all students each of their group's answer. She used verbal representations. For View 1, she wanted the representative to clarify whether the pressure is larger in air or water. However, the student did not know the answer. Another student gave her response and said that air has a greater pressure than water (View 2). She was the representative of the second group. Aishah asked the whole class whether they agreed or not that air has greater pressure than water. The class disagreed with that idea. Aishah verified and then rejected both View 1 and View 2 because neither one was particularly relevant to the idea of the weight loss [Code: AI-VOR-Aug 17-17 & AI-VOR-Aug 17-18]. View 1 and View 2 were students' alternative conceptions.

Aishah then moved to View 3, 4, 5, and 6. She asked the representatives of Group 3, 4, 5, and 6 to sketch and locate the buoyant force. Four representatives put arrows with upward signs. Their drawings were done in the researcher's

observation notes. These were picture representations. Figure 17 shows the free-body diagram of the buoyant force and the weight of the loads in water.

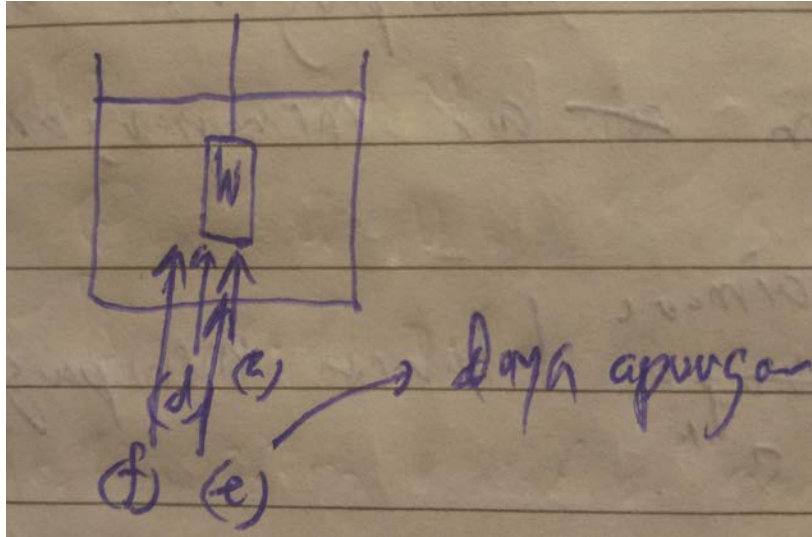


Figure 17. The free-body diagram of the buoyant force and the weight of the object.

(Translation: *daya apungan* = buoyant force)

[Code: AI-OBS-Aug 17-7]

In addition, Aishah asked students to determine another force. She asked students, “Is there any force left?” A student replied, “the object’s weight.” The symbol of W (in the drawing) represents the weight of the object.

Finally, Aishah verified Views 3, 4, 5, and 6 and accepted those ideas. She said that:

Aishah: Views 3, 4, 5, and 6 are correct. Why does the difference of weights of the loads occur? Because of buoyant force. There is no buoyant force in the air, but in the water there is. For example, if Aman wants to lift up Yusof, Aman can do it in water. That

ability is due to buoyant force. Do you know why a whale can swim?

Student₁: Buoyant force.

Aishah: Yes, that's it. Buoyant force. How can it swim?

Student₂: [With] its tail.

Aishah: How does the tail function?

Student₂: The tail makes a motion when swimming.

Aishah: That's right. It can swim due to the motion of the tail, and the buoyant force exerted on its body even though its body has a big mass.

[Code: AI-VOR-Aug 17-18]

Aishah told students that the loss of weight of the loads was due to the buoyant force. View 3 to View 6 were students' correct conceptions on the idea of the weight loss of an object when it submerges in a liquid like water.

Aishah then continued teaching Idea B regarding the loss of weight, using a commercial book. The book covered written questions on Archimedes' principle in quantitative and qualitative types. Aishah now used the questioning during whole class discussion activity for teaching Idea B. Figure 18 shows the picture of the weight loss retrieved from the book.

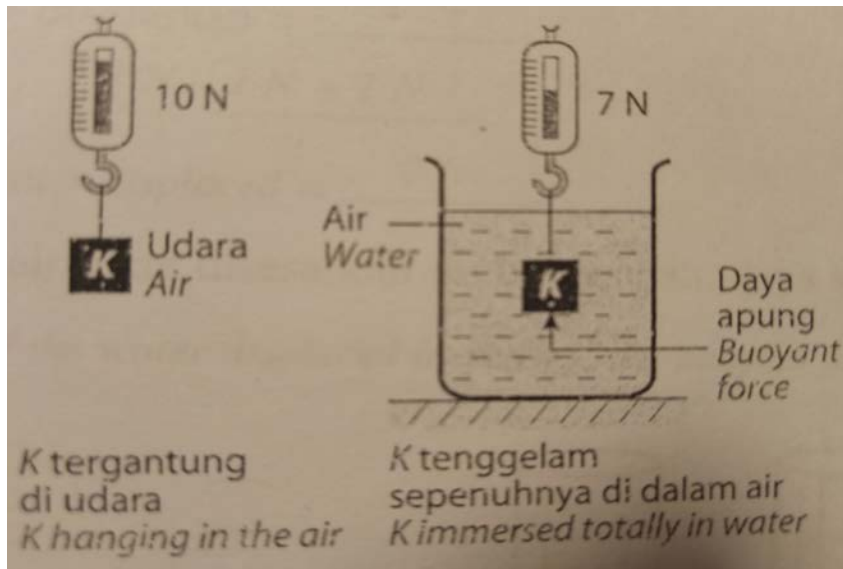


Figure 18. The idea of the weight loss of an object in the water.

[Code: AI-DOCM-Aug 17-10]

Aishah used the picture in Figure 18 to show students how an object, K, lost part of its weight when it was fully immersed in the water. The actual weight was 10 N, and the apparent weight (the weight in the water) was 7 N. Aishah asked students some questions regarding the loss of weight.

Aishah: Based on the diagram shown in your book (Figure 18), the magnitude of the buoyant force is equal to what?

Student₁: The actual weight.

Aishah: The actual weight? Wrong. The buoyant force is the apparent loss of the weight. The actual weight should be deducted from the apparent weight, or in other words, 10 N minus 7 N. What do we get?

Student₂: 3 N.

Aishah: Thus, the value of 3 N is equal to what?

Student₂: The buoyant force.

Aishah: Yes it is. Buoyant force.

[Code: AI-VOR-Aug 17-24]

The response from a student (student₁) indicated that he gave a wrong idea when suggesting the word “the actual weight” after Aishah asked the class about the buoyant force. She corrected her student’s idea by saying that the buoyant force is not the actual weight of an object, but the apparent loss of weight. She used the values of 10 N and 7 N in the book to represent the magnitude of the actual weight and the apparent weight. Hence, the weight loss is 3 N, determined by deducting 7 N from 10 N. The magnitude of the weight loss is also the magnitude of the buoyant force.

Teaching episode 3: Idea A. In the second lesson, Aishah taught students Idea A – the weight of the fluid displaced by an object is equal to the buoyant force. She used the activities of laboratory work, small group discussion after lab work, and questioning during whole class discussion. Representations used were: (1) VS, (2) WS, (3) P, (4) RLS, (5) F, and (6) M. Other representations were not evident, namely G and T.

She asked students to work in groups of six to carry out laboratory work on Idea A. The aim of the investigation was to study the relationship between the weight of liquid displaced and the buoyant force (Objective 1). Aishah provided specific instructions to students for doing the investigation.

- (1) Fill a Eureka can with water up to the level of the spout inside the Eureka can.
- (2) Take a small beaker and place it at the end of the spout of the Eureka can.
- (3) Carefully put the load hung from the spring balance into the Eureka can.
- (4) Measure the weight of water displaced using a digital balance.
- (5) Each group should report the reading of the weight of water displaced to the whole class.

[Code: AI-VOR-Aug 17-26 & AI-OBS-Aug 17-4]

Figure 16 shows the setup of the laboratory work. Aishah asked students to measure the weight of the water displaced in the small beaker in Figure 16 using an electronic balance. Each group came up with different answers for the magnitude of the weight of water displaced. However, many of them got the correct value of 0.20 N or around there. The variations of readings were due to errors when taking the readings of the weight of water displaced on the digital balance.

When each group had their answer about the magnitude of the weight of water displaced, Aishah talked to the whole class about the lab work.

Aishah: When we were immersing the load into the Eureka tin filled with water, what happened?

Student₁: The level of water rises.

Aishah: OK. Then?

Student₁: It flows out from the Eureka tin.

Aishah: Yes, that's right. The water flows out and goes to the small beaker. What is the relationship between the displaced water and the load? I want you to discuss in groups and come up with your own ideas.

In each group, members discussed their ideas on the relationship between the water displaced and the load (object). Aishah used verbal representations when talking to students about the water displaced (the water that flows out from the Eureka tin to the small beaker through the tin's spout). A representative from each group came in front to write their ideas on the whiteboard.

View 1: The buoyant force is equal to the weight of water displaced.

View 2: The volume of water increases.

View 3: The weight of the load increases, so the amount of water displaced increases.

View 4: The force on the load pushes water out from the Eureka tin.

View 5: The load pushes water to go out from the Eureka tin to the small beaker.

View 6: The volume of water displaced increases when the load enters into the Eureka tin.

[Code: AI-OBS-Aug 17-7]

The group's ideas on the whiteboard were written representations. Aishah verified each group's idea. For instance, she asked the group that suggested View 2, "How can the volume of water increase?" That group's representative replied, "Because when the load enters into the water, the volume of water increases." She initially accepted any ideas that students suggested without saying whether they were correct or wrong. She then started to confirm the groups' ideas by linking the lab work on the weight of water displaced (a manipulative representation) with a real-world situation on swimming (a real-world representation).

Aishah: If a person like you, Ahmad, swims in a bathtub, you can see how the water level of the bathtub increases. The increase is called "displaced water." If you refer to the experiment we did, some amount of water flows out from the Eureka tin. The water is called "displaced water." What is the weight of your water displaced then? How to get that answer? The actual weight is 2.0 N, and the apparent weight is 1.8 N, right? So, how much is the weight difference?

Student₁: 0.20 N.

Aishah: Yes, it is. 0.20 N. This is the weight loss. Then, the weight loss is equal to what?

Student₂: Buoyant force.

Aishah: *Yes it is. Buoyant force. The loss of weight is equal to the buoyant force.* Which answer could be used?

Student₃: View 1.

Aishah: Correct.

[Code: AI-VOR-Aug 17-15]

Aishah just accepted View 1. Other views were inaccurate or incomplete. However, Aishah did not mention that “the weight loss is equal to the buoyant force and is equal to the weight of liquid displaced” when interacting with the class. She had accepted View 1 that suggested, “the buoyant force is equal to the weight of water displaced” but Aishah missed the point of “the weight of water displaced” when replying to a student’s answer regarding the buoyant force (see Code: AI-VOR-Aug 17-15 at above with an *italic* sentence).

Aishah continued teaching Idea A using the activity of questioning during whole class discussion. She used a book to discuss Idea A with students. Figure 19 shows the picture of the weight of water displaced taken from the book.

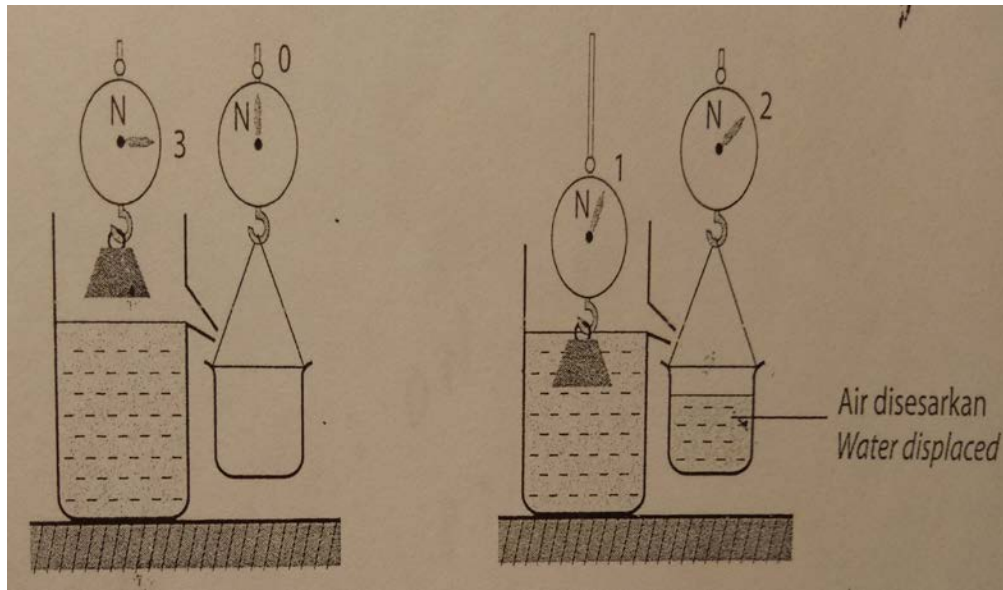


Figure 19. The idea of the weight of water displaced.

Aishah used the picture in Figure 19 to show students the idea of water displaced,

Idea A. She began a dialogue with students about the idea.

Aishah: The first question. Buoyant force is equal to...?

Student₁: The loss of weight.

Aishah: The loss of weight. Or, *the weight of the liquid displaced*.

Aishah added the point of “*the weight of the liquid displaced*” when replying to a student’s idea of the loss of weight. It is true that the buoyant force is equal to the loss of weight of an object. However, the current idea of teaching was the weight of the water displaced (Idea A) and not the weight loss (Idea B). Referring to the previous dialogue where Aishah did not mention the point regarding water displaced, she now tried to add the idea (Idea A).

She further discussed with students how to calculate the weight of water displaced. The diagram in Figure 19 shows that the reading of spring balance is 2

N for the weight of water displaced. The water displaced existed when the load was fully immersed in the beaker filled with water. The actual weight of the load is 3 N, but its weight becomes 1 N when it was completely submerged in water. The difference of weights is 2 N, which is equal to the magnitude of the water displaced, 2 N. Hence, the weight of water displaced is equal to the weight loss and is equal to the buoyant force.

In the same episode, Aishah taught students Idea A regarding the weight of liquid displaced and its relationship with the volume of liquid displaced (Objective 1). She used the activities of laboratory work, small group discussion after lab work, and questioning during whole class discussion. Representations used were VS, WS, P, RLS, F, and M, while other representations were not evident, G and T.

Aishah asked students to work in groups to run an investigation about the relationship between the weight of liquid displaced and the volume of liquid displaced. She gave specific instructions to students for doing the experiment:

- (1) Fill a measuring cylinder with 70 ml water.
- (2) Place the loads into the measuring cylinder.
- (3) Observe and record the readings of the loads' volume.
- (4) Report the loads' volume to the whole class.

[Code: AI-VOR-Aug 17-26 & AI-OBS-Aug 17-4]

Figure 20 shows the setting of the investigation.



Figure 20. The weight of liquid displaced and the volume of liquid displaced.

[Code: AI-DOCPH-Aug 17-2]

The investigation in Figure 20 was to show that the volume of an object, like a load, determines the volume of liquid displaced. When an object is fully immersed in a liquid, its volume is equal to the volume of water displaced. The volume of the object can be determined via the formula of $F_B = pVg$ where F_B is the buoyant force, p is the density of a liquid, V is the volume of a fully immersing object, and g is the gravitational acceleration.

The measuring cylinder in Figure 20 was to measure the volume of the load when it was wholly submerged in the water. The initial reading of the

water's volume was 70 ml. When the load was fully immersed, the water level increased. Each of the group reported their readings of the new volume. Many of them got 95 ml. Thus, the increase was 25 ml.

From the investigation, Aishah continued teaching Idea A using the questioning during whole class discussion activity. She made a dialogue with students regarding their investigations.

Aishah: OK. The original water's volume is 70 ml. Then, when you put the load into the measuring cylinder, the volume becomes 95 ml. Is it an increase of water's volume?

Student₁: No.

Aishah: No. It is not an increase in the volume of the water, but what? How much is the difference?

Student₂: 25 ml.

Aishah: 25 ml. So, what is the 25 ml?

Student₃: The volume of water displaced.

Aishah: The volume of water displaced, and it is equal to what?

Student₄: Weight of water displaced.

Aishah: Weight of water displaced. Correct.

The dialogue between Aishah and her students revealed that students had an alternative conception when saying that the volume of water displaced is equal to the weight of water displaced. The correct idea is the volume of water displaced is equal to the volume of an object when the object is fully immersed in water.

However, Aishah did not say to students that they were incorrect. She, in fact, agreed with the students' response. Nonetheless, she tried to fix the alternative conception later when discussing a question in the book. Figure 21 shows the diagram of a fully immersed object taken from the book used. The diagram includes a picture, a real-world situation, and written representations.

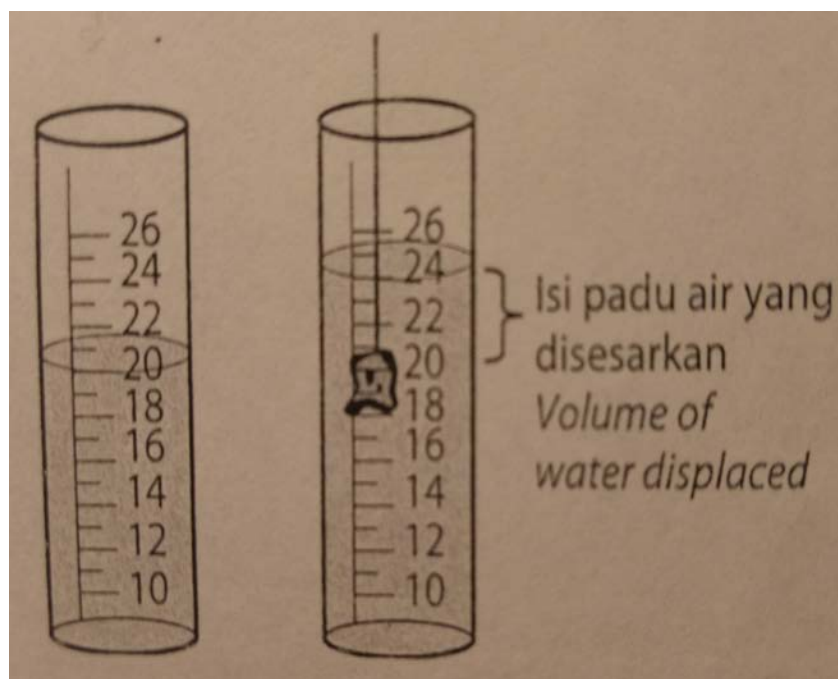


Figure 21. The volume of water displaced.

Aishah dialogued with students regarding the diagram shown in Figure 21.

Aishah: See question (d). The volume of the object in water is equal to what?

Student₁: The volume of water.

Aishah: The volume of water what?

Student₁: Water displaced.

Aishah: Correct. The volume of water displaced is equal to the volume of the object in a full immersion case. If we use a load, then it is the volume of the load.

[Code: AI-VOR-Aug 17-37]

For a fully immersed object, its volume is equal to the volume of water displaced. Aishah's and her students' idea were correct. Aishah seemed to fix or clarify the alternative conception that happened in the previous dialogue.

Teaching episode 4: Idea C. In the same lesson (lesson two), Aishah taught students Idea C regarding flotation – the weight of an object is equal to the weight of the fluid displaced (Objective 1). She used the lecture activity. The representations used were VS and F.

Aishah lectured to students about Idea C on flotation:

If an object is floating, part of its body is in water while another part in air, and the buoyant force exerted on the object is equal to the object's weight. That is why it floats. If its weight is 10 N, then the buoyant force is also 10 N.

[Code: AI-VOR-Aug 17-41 & AI-VOR-Aug 17-42]

She provided a simple lecture regarding flotation. Aishah gave an example of flotation by providing 10 N as the value of an object's weight and the buoyant force.

Teaching episode 5: Idea D. In the same lesson (lesson two), Aishah taught students Idea D regarding immersion – in an immersion case, the weight of

an object is greater than the buoyant force (Objective 1). She adopted the activity of questioning during whole class discussion to teach students Idea D. The representation used were VS and F, while other representations of WS, P, RLS, G, T, and M were not used.

A short dialogue between Aishah and students was captured.

Aishah: An object moves in the downward direction in a liquid.

There is the weight of an object and the buoyant force. What does this mean?

Student₁: Its weight is greater than the buoyant force.

Aishah: Correct. The object's weight is larger than the buoyant force.

[Code: AI-VOR-Aug 17-43]

An immersion case applies the idea that the magnitude of the buoyant force is lesser than the weight of an object. Aishah's student told the truth when saying that the magnitude of the weight of an object moving downward is higher than the buoyant force exerted on the object.

Teaching episode 6: Idea B and Idea A. In the same lesson (lesson two), Aishah moved to discussing quantitative questions in the book she used. She first discussed with the whole class a question regarding the weight loss of an object (Idea B) and the weight of liquid displaced (Idea A). She used the questioning during whole class discussion activity to teach students both ideas.

Representations used were VS, WS, RLS, and F, while other representations were not used, namely M, G, T, and P.

Figure 22 shows a quantitative question regarding the weight of liquid displaced, taken from the book (Objective 3). The question was in dual languages, Malay and English.

Latihan/Exercises

$$(g = 10 \text{ m s}^{-2})$$

1 Sebuah blok yang keras digantung di udara dengan menggunakan benang dari neraca spring. Neraca spring tersebut memberikan bacaan 65 N. Apabila blok itu tenggelam sepenuhnya di dalam air, neraca spring memberikan bacaan 30 N.

A solid block is suspended in air by a thin thread from a spring balance. The spring balance gives a reading of 65 N. When the block is completely submerged in water, the spring balance gives a reading of 30 N.

(a) Tentukan daya keapungan yang dikenakan oleh air pada blok tersebut.

Determine the buoyant force exerted by the water on the block.

(b) Berapakah berat air yang disesarkan oleh blok tersebut?

What is the weight of water displaced by the block?

(c) Tentukan isi padu air yang disesarkan oleh blok. [Ketumpatan air = $1\,000 \text{ kg m}^{-3}$]

Determine the volume of water displaced by the block. [Density of water = $1\,000 \text{ kg m}^{-3}$]

Figure 22. The quantitative question on Idea B and Idea A.

The question in Figure 22 asked students to find the value of the buoyant force exerted on an object, a solid block, which has the actual weight of 65 N. When the block was completely immersed in water, its weight becomes 30 N. The question then asked students to find the magnitude of the weight of water displaced by the block. Finally, students were asked to find the volume of water displaced by the block. Students were required to apply Idea B and Idea A of Archimedes' principle to answer this question.

Aishah engaged in a dialogue with the whole class about the question in Figure 22.

Aishah: A solid block is suspended in air by a thin thread from a spring balance. The spring balance gives a reading of 65 N. What does the value mean?

Student₁: The actual weight.

Aishah: The actual weight. Please write it, the actual weight is 65 N. OK. When the block is completely submerged in water, the spring balance gives a reading of 30 N. What does the magnitude mean?

Student₂: The apparent weight.

Aishah: Correct. The apparent weight is 30 N. See the question. Determine the buoyant force exerted by the water on the block. How to find the buoyant force? Buoyant force is equal to what?

Student₃: The actual weight minus the apparent weight.

Aishah: Yes it is. The buoyant force is equal to the actual weight minus the apparent weight. So, 65 N deducted by 30 N. What is the magnitude of the buoyant force?

Student₄: 35 N.

Aishah: Yes it is. 35 N. The next question, what is the weight of water displaced by the block?

Student₅: 35 N.

Aishah: Yes it is. 35 N too. Clever. OK. The question (c). Determine the volume of water displaced by the block. If we want the value of the volume of water displaced, what is the formula to use?

Student₁: $F_B = \rho Vg$.

Aishah: Correct. Hence, $F_B = \rho Vg$. What is ρ ?

Student₂: The density.

Aishah: What is V ?

Student₃: The volume.

Aishah: What is g ?

Student₄: Gravity.

Aishah: What is F_B ?

Student₅: Buoyant force.

Aishah: Yes, it is. Do we already know the value of the buoyant force?

Student₆: Yes.

Aishah: Yes. What is the value of the buoyant force?

Student₇: 35 N.

Aishah: What does the question ask for?

Student₇: The volume.

Aishah: The volume. How to find the volume?

Student₇: $V = F_B / \rho g$.

Aishah: Correct. What answer did you get?

Student₇: 0.0035.

Aishah: That's it. The unit?

Student₇: m^3 .

Aishah: Yes, that's right. The unit is m^3 because it is a volume.

[Code: AI-VOR-Aug 17-45, AI-VOR-Aug 17-46, & AI-VOR-Aug
17-47]

The very long dialogue between Aishah and her students shows how Aishah guided her students to solve the quantitative problem integrating Idea B and Idea A step-by-step. She first asked students to find the value of the buoyant force by deducting 30 N (the apparent weight) from the value of 65 N (the actual weight of the block). The difference between the weights equals the loss of weight which is equal to the buoyant force. This was Idea B. To calculate the magnitude of the water displaced by the block, students needed to know Idea A: namely, the weight of liquid displaced is equal to the buoyant force. Since the magnitude of

the buoyant force was known, 35 N, then the weight of the water displaced was also 35 N. The final question, 1(c), required students to apply the formula of the weight of water displaced where the buoyant force, F_B , is equal to the weight of water displaced, pVg . This was Idea A regarding the weight of liquid displaced. Knowing that the value of F_B is 35 N, p is 1000 kg m^{-3} , and g is 10 m s^{-2} , students can find the value of the volume of water displaced by the block using the formula of $F_B = pVg$. The volume of water displaced is 0.0035 m^3 . This question requires students to combine their understandings on Idea B and Idea A of the Archimedes' principle.

Teaching episode 7: Idea C. In the same lesson (lesson two), Aishah taught students Idea C regarding flotation. She used the questioning during whole class discussion activity to teach the idea. Representations used were VS, WS, P, RLS, and F. Other representations were not evident, namely G, T, and M.

Figure 23 shows a quantitative question regarding flotation, taken from the book (Objective 2 and 3). The question was in two languages, Malay and English.

Rajah menunjukkan sebiji belon berjisim 200 kg sedang terapung pada kedudukan pegun di udara. Berapakah daya apung belon itu?
The diagram shows a balloon of mass 200 kg floating in a stationary position in the air. What is the buoyant force on the balloon?

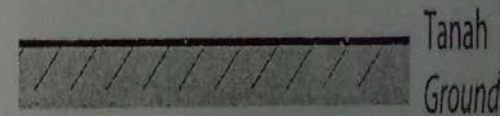
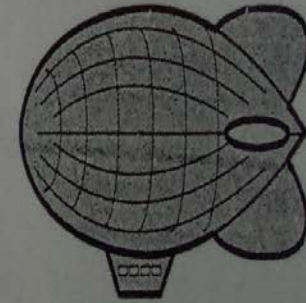


Figure 23. A quantitative question on Idea C regarding flotation.

The question presented in Figure 23 required students to apply Idea C: the buoyant force is equal to the weight of an object when the object is floating. The script below shows Aishah's dialogue with students about this question.

Aishah: OK. Referring to the question, what does the object have?

Student₁: Mass.

Aishah: It has mass. What makes it float?

Student₂: Buoyant force.

Aishah: Buoyant force, F_B . When it is in a stationary position like in the question, what is the formula to use?

Student₃: The flotation formula.

Aishah: The flotation formula. So, the buoyant force is equal to the weight of the object. However, does the question give the value of the weight?

Student₄: No.

Aishah: What does the question provide?

Student₅: The mass.

Aishah: The mass. What is the formula of weight?

Student₆: $W = mg$.

Aishah: OK. Please calculate. How much did you get for the weight?

Student₆: 2000 N.

Aishah: Right. 2000 N.

[Code: AI-VOR-Aug 17-48]

The dialogue above reveals that Aishah said to students that the buoyant force is equal to the weight of an object in a flotation case. That is the crucial idea of flotation, Idea C. Students needed to convert the value of the mass of 200 kg to weight, which is 200 kg multiplied by 10 m s^{-2} using the formula of weight, $W = mg$, where W is weight, m is mass, and g is gravitational acceleration. The weight of the balloon is 2000 N. Realizing that this is a case of flotation, we can know that the weight of 2000 N is equal to the magnitude of the buoyant force exerted on the balloon. Therefore, the buoyant force is 2000 N.

Teaching episode 8: Idea B and Idea A. In the same lesson (lesson two), Aishah taught students Idea B and Idea A. She adopted the questioning during whole class discussion activity to teach both ideas. Representations used were VS, WS, RLS, and F, while other representation, specifically G, T, P, and M were not used.

Figure 24 shows a quantitative question regarding Idea B and Idea A, taken from the book (Objective 3). The question was in two languages, Malay and English.

Suatu jasad mempunyai berat 20 N di udara dan 15 N di dalam cecair. Jika isi padu cecair yang tersesar adalah $5 \times 10^{-4} \text{ m}^3$, berapakah ketumpatan cecair tersebut?

A body has a weight of 20 N in air and 15 N in a liquid. If the volume of the liquid displaced is $5 \times 10^{-4} \text{ m}^3$, what is the density of the liquid?

Figure 24. The quantitative question on Idea B and Idea A.

The question in Figure 24 required students to apply Idea B regarding the loss of weight of an object and Idea A regarding the formula of the weight of liquid displaced.

A dialogue between Aishah and her students was captured.

Aishah: Ok. See the question. A body has a weight of 20 N in the air and 15 N in a liquid. What is 20 N?

Student₁: The actual weight.

Aishah: Correct. Please write it. Then, what is 15 N?

Student₂: The apparent weight.

Aishah: That's it. OK. If the volume of the liquid displaced is $5 \times 10^{-4} \text{ m}^3$, what is the density of the liquid? What does the question ask for?

Student₃: The density.

Aishah: How to find the density? Density, ρ , is equal to what?

Student₄: $\rho = F_B/Vg$.

Aishah: Can we get the buoyant force, F_B ?

Student₅: Yes, we can.

Aishah: How to get the buoyant force?

Student₆: Deduction.

Aishah: Deduction of what?

Student₇: 20 N minus 15 N.

Aishah: That's it. Good. Please calculate.

[Code: AI-VOR-Aug 17-49]

Aishah guided students to solve the questions on Idea B and Idea A. Students needed to find the loss of weight of the body (Idea B) to get the magnitude of the buoyant force. Then, by getting the value of the buoyant force, students now should be able to use Idea A where the buoyant force is equal to the weight of liquid displaced or $F_B = \rho Vg$. The value of the buoyant force is 5 N, 20 N – 15 N. This is Idea B. For Idea A, students used the formula of the Archimedes' principle and substituted the value of the buoyant force, 5 N, the volume of the liquid displaced, $5 \times 10^{-4} \text{ m}^3$, and the gravitational acceleration, 10 m s^{-2} . Thus, students can get the value of the density of the liquid as 1000 kg m^{-3} using Idea 2 to figure out the weight of liquid displaced, $F_B = \rho Vg$.

Teaching episode 9: Idea A and Idea C. In the third lesson, Aishah taught students Idea A (the weight of liquid displaced) and Idea C (flotation). She utilized the questioning during whole class discussion activity to teach both ideas. Representations used were VS, WS, RLS, F, and P while other representations were not used, namely G, T, and M.

Figure 25 shows a quantitative question regarding Idea A and Idea C, taken from the book (Objective 3). The question was in dual languages, Malay and English.

Rajah menunjukkan satu tabung uji berjisim 0.012 kg dengan diameter seragam dan luas keratan rentas $4 \times 10^{-4} \text{ m}^2$, dan diisi dengan pasir, supaya ianya terapung menegak di dalam bikar yang berisi air dengan kedalaman 0.08 m.

[Ketumpatan air ialah $1\,000 \text{ kg m}^{-3}$]

The diagram shows a test-tube of mass 0.012 kg with uniform diameter and cross-sectional area $4 \times 10^{-4} \text{ m}^2$, and it is filled with sand, so that it floats vertically in a beaker containing water at a height of 0.08 m. [Density of water is $1\,000 \text{ kg m}^{-3}$]

Tentukan/Determine

- (a) daya keapungan terhadap tabung uji.
the buoyant force on the test tube.
- (b) berat pasir di dalam tabung uji.
the weight of the sand in the test tube.

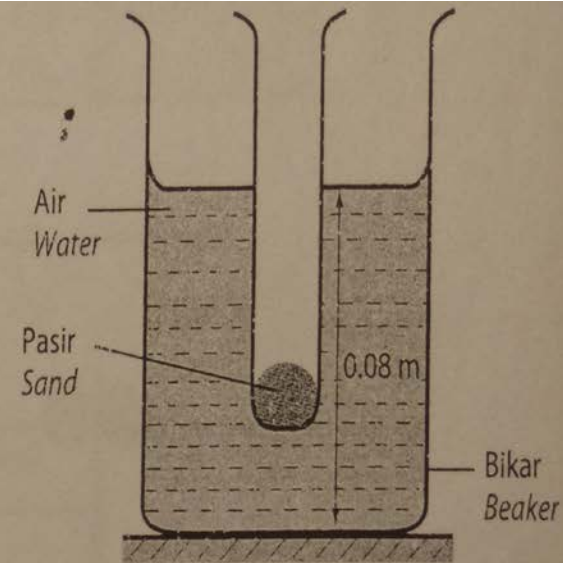


Figure 25. The quantitative question on Idea A and Idea C.

The question in Figure 25 required students to apply two ideas, Idea A and Idea C. Regarding the value of the buoyant force exerted on the test tube, students should apply Idea A – the buoyant force is equal to the weight of liquid displaced, $F_B = \rho Vg$. Moreover, students should be able to apply Idea C where the buoyant force is equal to the weight of a floating object. Since the tube is floating, Idea C applies in this case. Aishah asked a student, Leman, to solve the problem on the whiteboard. She then discussed the problem and solution with the whole class.

A dialogue between Aishah and her students was captured regarding the question in Figure 24.

Aishah: OK. The volume of the test tube comes from the cross-sectional area of $4 \times 10^{-4} \text{ m}^2$ multiplied by the depth of the test tube in the water, which is 0.08 m. So, we can get the volume. Then, you apply the formula of $F_B = \rho Vg$. ρ is 1000 kg m^{-3} , V is 0.000032 m^3 , and g is 10 m s^{-2} . So, you will get 0.32 N. That is question (a). For question (b), Leman, your answer is wrong. The mass given is the mass of the test tube, which is 0.012 kg. It is not the mass of the test tube with the sand in the test tube. So, what is the mass of the test tube?

Student₁: 0.012 kg.

Aishah: How to get its weight? Multiplied by 10 m s^{-2} . How much you get?

Student₁: 0.12 N.

Aishah: OK. That is the weight for the test tube only. We know that the buoyant force is equal to what?

Student₂: The weight of liquid displaced.

Aishah: The weight of liquid displaced or the weight of an object. We already got the value of the buoyant force as 0.32 N. This buoyant force is equal to the weight of the object that is the weight of the test tube **and** the sand in the test tube. Understand? So, we already know the buoyant force and the weight of the test tube. Can we find the weight of the sand in the test tube? The weight of the sand is equal to the buoyant force minus the weight of the test tube or 0.12 N from 0.32 N deducted. So, we get the weight of the sand in the test tube as 0.2 N.

Aishah's dialogue with her students revealed that the question in Figure 25 was quite complex. Regarding question (a), students should know how to apply the formula of Idea A where the buoyant force is equal to the weight of liquid displaced, $F_B = \rho Vg$. However, students seemed to find it difficult to solve question (b) because it required them to apply Idea C where the buoyant force is equal to the weight of a floating object, which is the weight of the test tube and the sand in the test tube. Aishah reminded her students that the question only provided the mass of the test tube, 0.012 kg and not the mass of the test tube with the sand. By applying Idea C, the weight of the sand in the test tube can be obtained by deducting the magnitude of the buoyant force, 0.32 N, by the weight

of the test tube, 0.12 N. The weight of the test tube is obtained by multiplying 0.012 kg by 10 m s^{-2} ($W = mg$). Hence, the weight of the sand in the test tube is 0.2 N.

Teaching episode 10: Idea A and Idea B. In the same lesson (lesson three), Aishah taught students Idea A (the weight of liquid displaced) and Idea B (the loss of weight). She used the questioning during whole class discussion activity to teach both ideas. Representations used were VS, WS, RLS, and F, while representations of P, M, G, and T were not used.

Figure 26 shows a quantitative question regarding Idea A and Idea B, taken from the book (Objective 3). The question was in two languages, Malay and English.

Sebuah objek mempunyai isi padu $5 \times 10^{-4} \text{ m}^3$ digantung pada neraca spring di udara. Bacaan pada neraca spring ialah 8 N. Jika objek itu ditenggelamkan sepenuhnya ke dalam cecair yang berketumpatan 600 kg m^{-3} , tentukan bacaan neraca spring sekarang.

An object with a volume of $5 \times 10^{-4} \text{ m}^3$ is hung from a spring balance in the air. The reading of the spring balance is 8 N. If the object is immersed fully in a liquid with a density of 600 kg m^{-3} , determine the reading of the spring balance now.

Figure 26. The quantitative question on Idea A and Idea B.

The question in Figure 26 asked students to find the apparent weight of an object that has the volume of $5 \times 10^{-4} \text{ m}^3$ and the actual weight of 8 N. The object is fully immersed in a liquid that has the density of 600 kg m^{-3} .

The script below is from the dialogue between Aishah and her students about the question.

Aishah: How to find the buoyant force?

Student₁: The actual weight minus the apparent weight.

Aishah: We do not know the magnitude of the buoyant force now.

How to find it?

Student₂: Use the formula of $F_B = \rho Vg$.

Aishah: OK. $F_B = \rho Vg$. What is the value of ρ ?

Student₃: 600 kg m^{-3} .

Aishah: What about V ?

Student₄: $5 \times 10^{-4} \text{ m}^3$.

Aishah: OK. Please calculate the buoyant force.

Student₄: 3 N.

Aishah: OK. Using the value of the buoyant force as 3 N, please calculate the value of the apparent weight.

Student₅: 5 N.

Aishah: 5 N. OK. Correct.

[Code: AI-VOR-Aug 24-4]

Students were required to apply Idea A where the buoyant force is equal to the weight of liquid displaced, $F_B = \rho Vg$. When ρ is equal to 600 kg m^{-3} , V is equal to $5 \times 10^{-4} \text{ m}^3$, and g is 10 m s^{-2} , students got the value of the buoyant force, F_B , as 3 N. Then, students needed to apply Idea B where the buoyant force is equal to the weight loss. The loss of weight is calculated by deducting the weight of an object in air and in a liquid. Since the magnitude of the buoyant force was obtained, 3 N, and the magnitude of the actual weight is 8 N, thus the value of the apparent weight (the weight of an object in a liquid) is equal to 8 N minus 3 N, which is equal to 5 N.

Aishah stopped doing the quantitative questions here. She reminded students to pay attention to those quantitative questions because they involved many ideas and formula, especially Idea B: the buoyant force is equal to the loss of weight, and Idea A: the buoyant force is equal to the weight of liquid displaced or $F_B = \rho Vg$. Aishah hoped that her students could diligently use those ideas and formulae when solving quantitative questions on Archimedes' principle because they are complex [Code: AI-VOR-Aug 24-7].

Teaching episode 11: Idea C. In the same lesson (lesson three), Aishah taught students Idea C regarding flotation. She used the questioning during whole class discussion activity to teach Idea C. Representations used were VS, WS, P, and RLS. Aishah used the book that she purchased from a private company for teaching students applications of Archimedes' principle (Objective 2). She asked students to fill in the blank sentences provided in the book.

One application of flotation is a ship. A dialogue between Aishah and her students was captured.

Aishah: A ship made of steel will float on water. Why can the ship float, but a solid steel will sink?

Student₁: The density.

Aishah: The density? Incorrect.

Student₂: The buoyant force.

Aishah: Other than that?

Student₃: The large surface area.

Aishah: Yes, that's it. What about the shape of a ship?

Student₄: Large shape.

Aishah: Right. Its shape has a large area. By having a large area, it can balance its massive weight. There is a buoyant force exerted on the ship.

[Code: AI-VOR-Aug 24-8]

Aishah's dialogue revealed that Idea C applies in the case of flotation of a ship. The ship can float due to the buoyant force exerted on the ship, and the ship has a large surface area that can displace an enormous volume of water.

Another application of flotation that Aishah taught had to do with floating boats. Idea C regarding flotation applies (Objective 2). Aishah used the questioning during whole class discussion activity to teach about boats. Figure 27

shows two situations regarding flotation of boats. This information was taken from the book that Aishah used.

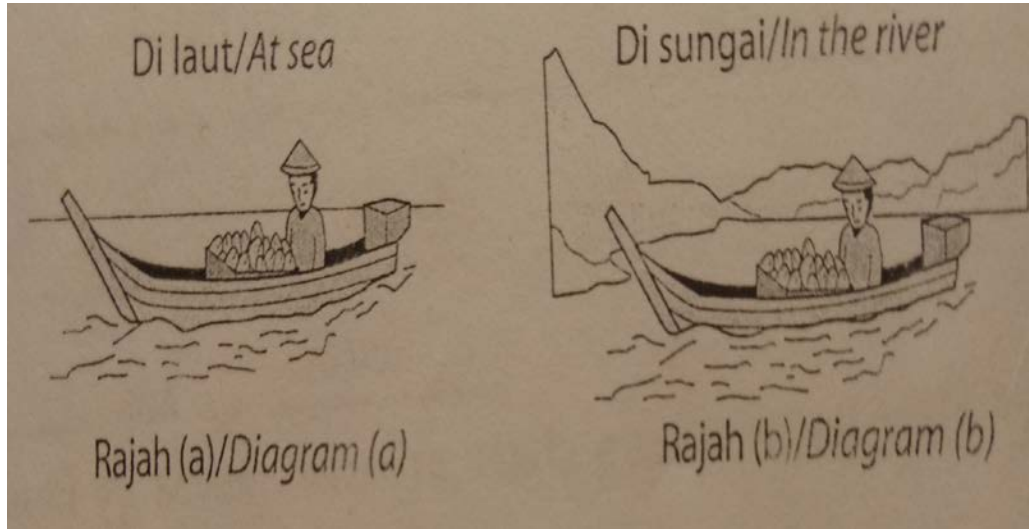


Figure 27. The application of Idea C and Idea A – boats.

[Code: AI-DOCM-Aug 24-9]

A dialogue between Aishah and her students regarding the boats in Figure 27 was captured as follows:

Aishah: A boat will submerge deeper in the river than in the sea.

Why?

Student₁: The density.

Aishah: The density. What has a higher density?

Student₁: Seawater.

Aishah: The seawater has a higher density. So, will the boat submerge or float more on the sea?

Student₂: Float.

Aishah: Float. When the density of a liquid is high, the buoyant force will become what?

Student₃: Lower.

Aishah: Lower?

Student₄: Greater.

Aishah: It becomes greater, right. If the density of a liquid is lower, the buoyant force is smaller in magnitude.

Aishah told her students that the density of a liquid plays a role in determining the magnitude of a buoyant force. Idea A where the buoyant force, F_B is equal to pVg (the weight of liquid displaced) implies that the bigger the value of p (the density of a liquid), the greater the buoyant force. Idea C regarding flotation also applies with the boats.

Teaching episode 12: Idea A and Idea C. In the same lesson (lesson three), Aishah taught students Idea A and Idea C. She used the application of ships carrying loads, to teach students the idea of the weight of liquid displaced (Objective 2). She used the representations of VS, WS, P, and RLS. She used the questioning during whole class discussion activity to teach about ships moving with different amount of loads. Figure 28 shows two ships, A and B. The ship B carries extra loads than the ship A. The figure was taken from the book that Aishah used. She asked students to fill in the blank sentences provided in the book.

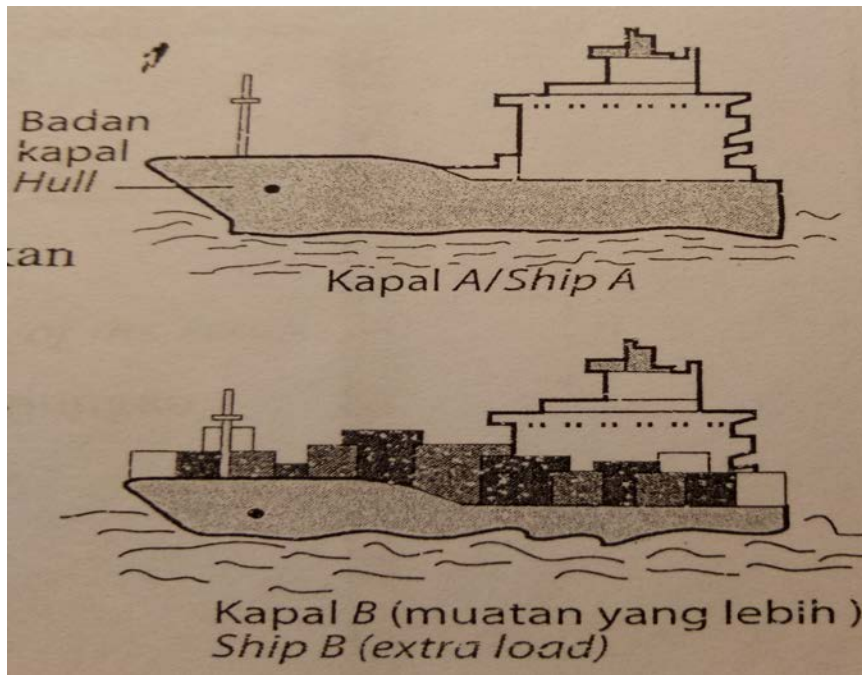


Figure 28. The application of Ideas A and C – ships carrying loads.

Aishah dialogued with students regarding ships carrying loads in Figure 28.

Aishah: The hull of a ship will sink deeper in the water if the extra weight is put into it. Comparing two ships, one with no loads and one full of loads, which ship will sink more?

Student₁: The empty ship.

Aishah: Is it true?

Student₂: The ship carries extra loads.

Aishah: Why?

Student₂: More loads.

Aishah: More loads. Why more loads?

Student₂: More weight.

Aishah: Haaa. Its weight is larger. When the weight is bigger, will the buoyant force become lower or higher?

Student₃: High.

Aishah: No. It becomes lower. OK. This is an empty ship and a ship carrying loads. Which one can float better?

Student₄: The ship with extra loads.

Aishah: No. The empty ship can float better. Which one has a bigger buoyant force?

Student₅: The empty ship.

Aishah: Yes, it does. The buoyant force is higher for the empty ship and is lower for the ship carrying extra loads. When the weight increases, will the buoyant force become greater or smaller?

Student₆: Smaller.

Aishah: Why?

Student₆: The buoyant force cannot sustain the weight.

Aishah: OK. Wait. I am rethinking. Previously, I said that the buoyant force decreases when the loads increase, right? Please reconsider it. If the buoyant force is lower and the weight is higher, will it sink?

Student₇: It will.

Aishah: It will sink. Thus, when the ship has extra loads, it needs a buoyant force that is greater or lower?

Student₇: A greater buoyant force.

Aishah: Yes, that's right. Because it needs to sustain the larger weight due to the extra loads carried. Hence, when the ship carries many loads, the buoyant force exerted on the ship is greater. In other words, if the weight increases, the buoyant force increases to sustain the larger weight. If the weight is low, the buoyant force is also low.

[Code: AI-VOR-Aug 24-8]

Aishah was trying to clarify a confusion regarding the application of Idea A. She revised her initial idea where she said earlier that the buoyant force is lower when the weight of the ship increases due to extra loads. She then corrected herself and said that when the ship has extra loads, the weight of the ship increases, and the buoyant force increases to sustain a bigger weight. That is how the ship can displace more seawater. In this context, the ship carrying extra loads will sink if its weight is larger than the buoyant force.

In the same episode, Aishah taught Idea A. She used the application of the Plimsoll symbol on a ship to teach students the idea (Objective 2). She used the questioning during whole class discussion activity. Figure 29 shows the Plimsoll lines on a ship. The figure was taken from the book that Aishah used. She asked students to fill in the blank sentences provided in the book.

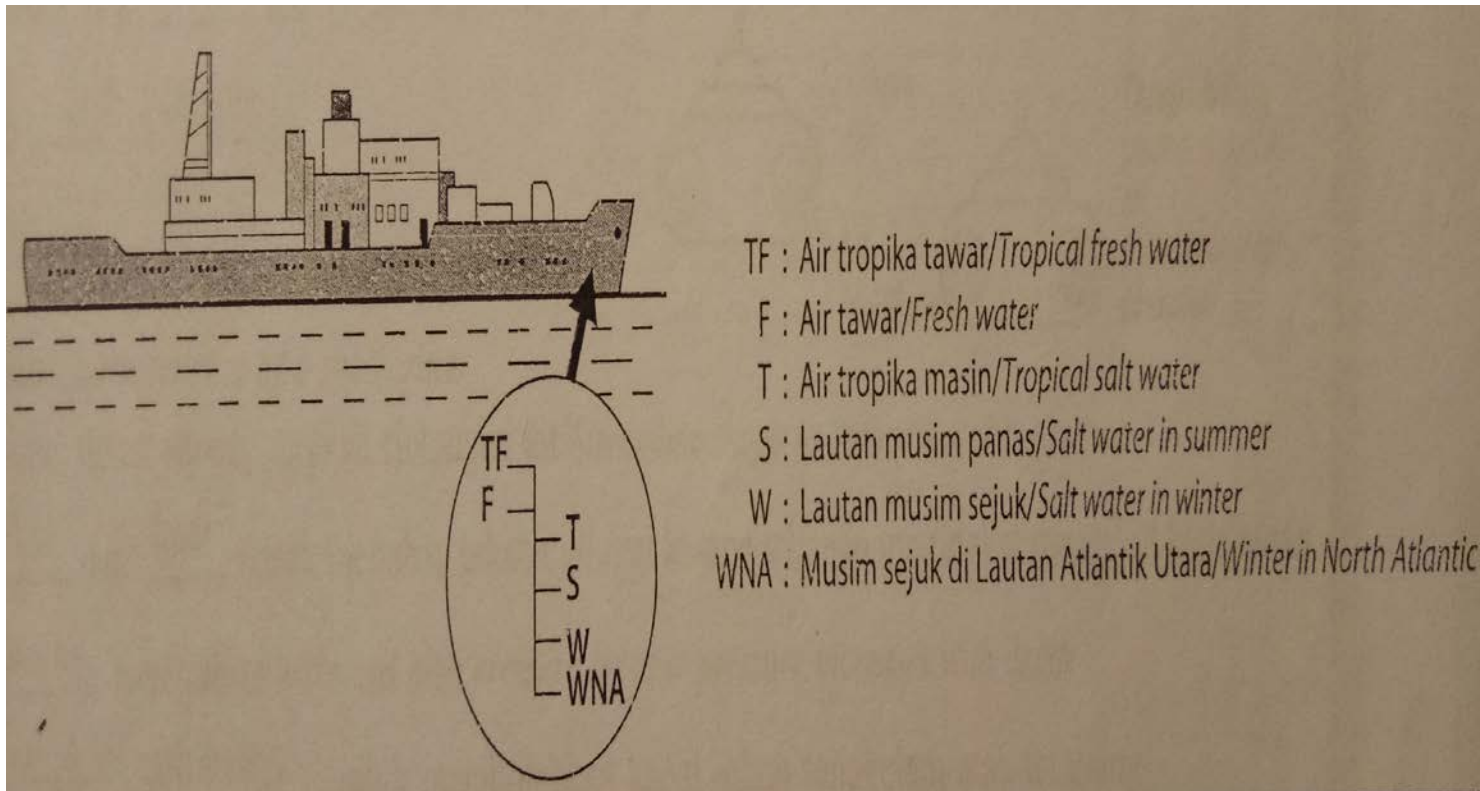


Figure 29. Plimsoll symbols on a ship.

Aishah explained the Plimsoll symbols to the students.

Aishah: All of the symbols have different meanings. TF is for Tropical Fresh Water, F is for Fresh Water, T is for Tropical Salt Water, S is for Salt Water in Summer, W is for Salt Water in Winter, and WNA is for Winter in North Atlantic. If a ship now is at TF, the ship must immerse only to the level of the TF symbol. It cannot sink lower than the TF symbol because the ship will be totally submerged. So, what should the ship's crew do?

Student₁: Throw out loads.

Aishah: Correct. Throw out loads. Why?

Student₁: To make the ship float at the TF level.

Aishah: That's right.

[Code: AI-VOR-Aug 24-10]

The Plimsoll symbols are used to inform the crews the appropriate depth a ship can submerge to. The symbols are created based on types of oceans and different seasons. Aishah said to students that the crews must adhere to the symbol when the ship is traveling on different seas in different seasons. This application of Plimsoll lines applies Idea A relating to the weight of liquid displaced, particularly the role of the density of a liquid, ρ , in the equation of Archimedes' principle, $F_B = \rho Vg$. Different seas have different densities; hence they affect the magnitude of the weight of liquid displaced by the ship.

Teaching episode 13: Idea C and Idea D. In the same lesson (lesson three), Aishah taught students Idea C and Idea D regarding flotation and immersion. She used the application of a submarine to teach students both ideas (Objective 2). The teaching activity used was questioning during whole class discussion. Aishah used representations of VS, WS, P, and RLS. Figure 30 shows the image of a submarine, taken from the book that she used. She wanted students to fill in the blanks in the sentences in the book used (about the submarines).

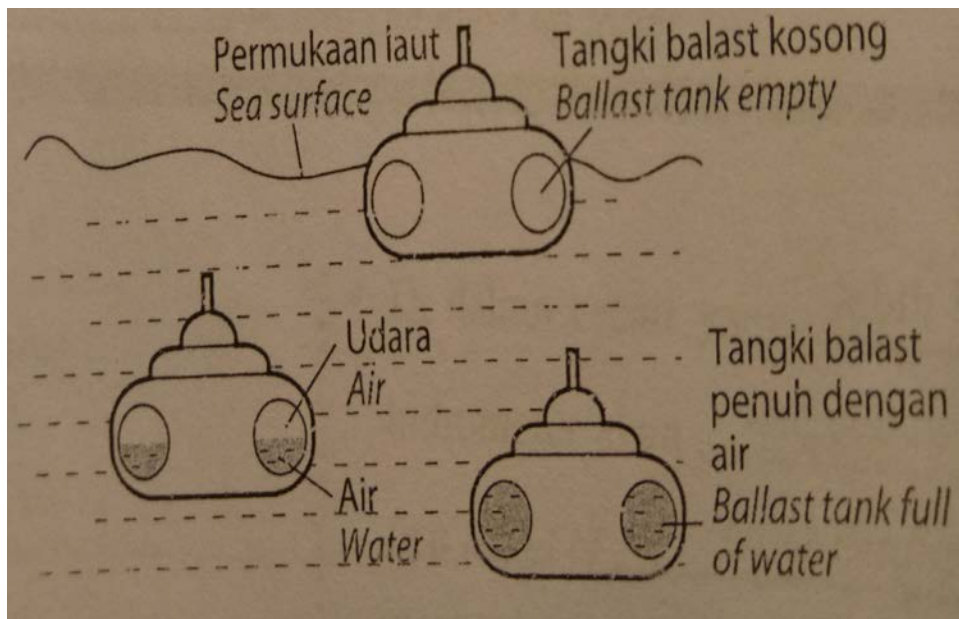


Figure 30. The application of immersion, submarines.

A dialogue between Aishah and students was captured as follows:

Aishah: OK. See there. A submarine. How to submerge the submarine?

Student₁: Fill with water.

Aishah: Good. Clever. How to make the submarine submerge deeper?

Student₂: Add more water until full.

Aishah: Yes. The ballast tank of the submarine needs to fill completely with water. When the submarine submerges deeper and deeper, what happen to the buoyant force?

Student₃: Smaller.

Aishah: Yes. The buoyant force is smaller than the weight of the submarine. However, if the submarine is going higher and higher to the sea surface and making the ballast tank empty, which one is greater? The buoyant force or the weight of the submarine?

Student₄: The buoyant force.

Aishah: Yes, that's right. OK.

[Code: AI-VOR-Aug 24-11]

What Aishah said was true. A submarine needs to be filled with more water if it is to submerge in the ocean deeper. Adding more water to the ballast tanks increases the submarine's weight. The weight of the submarine is then greater than the buoyant force exerted on the submarine. However, when the submarine wants to float, it must pump out water and make its weight equal to or less than the buoyant force. The submarine case applies Idea C and Idea D, flotation and immersion.

Teaching episode 14: Idea C. In the same lesson (lesson three), Aishah taught students Idea C regarding flotation. She used an application of flotation, a hot air balloon, to teach students Idea C (Objective 2). She used the questioning during whole class discussion activity to teach the flotation idea. Aishah used the representations of VS, WS, P, and RLS. Figure 31 shows the application of flotation, hot air balloons, taken from the book Aishah used. She asked students to fill in the blank sentences provided in the book.

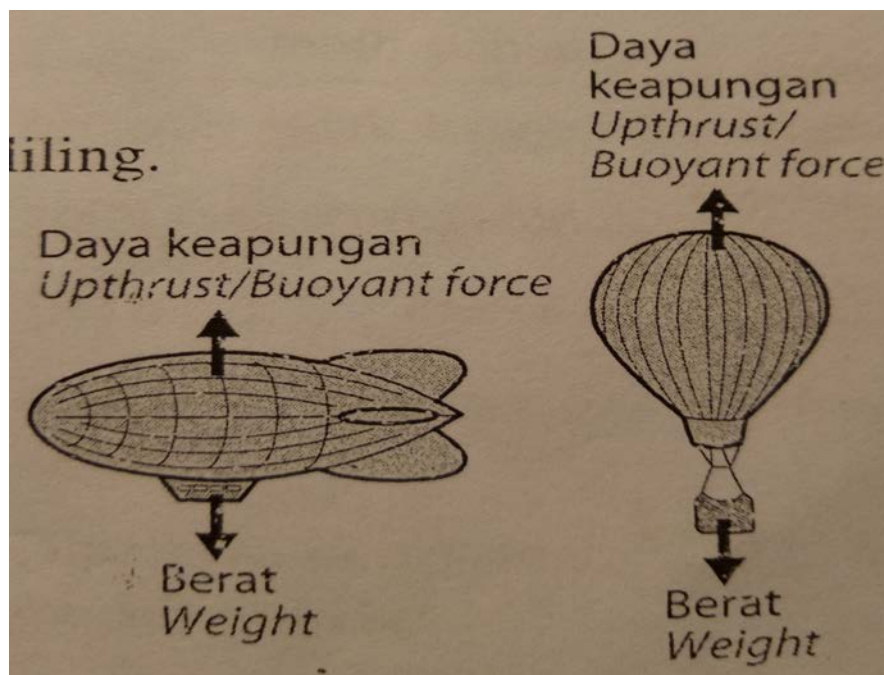


Figure 31. The application of flotation, hot air balloons.

Aishah explained the hot air balloons to the students.

Aishah: Hot air balloons. What is the gas inside the balloons?

Student₁: Helium.

Student₂: Hydrogen.

Aishah: Helium, not hydrogen. How to make the balloons float?

Student₃: Heat the helium gas.

Aishah: OK. What happens then?

Student₃: It floats.

Aishah: How can it float?

Student₃: The gas expands.

Aishah: What happens to the particles of the gas then?

Student₃: Less dense.

Aishah: Haa. Because the density of the gas becomes lower when it is heated. The distances between particles become far. When the gas becomes less dense, the balloon floats. It goes up in the air.

[Code: AI-VOR-Aug 24-12]

In the hot air balloon example, Idea C regarding flotation applies. Aishah told students that the hot air balloon could float because the density of the helium gas inside the balloon is less dense when the gas is heated. Heating the gas makes it less dense because the distances between the gas particles become far with each other. Therefore, the balloon goes up and floats in the air.

Teaching episode 15: Idea A. In the same lesson, Aishah taught students Idea A regarding the weight of liquid displaced. She used the application of a hydrometer to teach students Idea A. Aishah used the teaching activity of questioning during whole class discussion. She adopted the representations of VS, WS, P, and RLS. Figure 32 shows the application of a hydrometer, taken from the

book Aishah used. She asked students to fill in the blanks in sentences provided in the book.

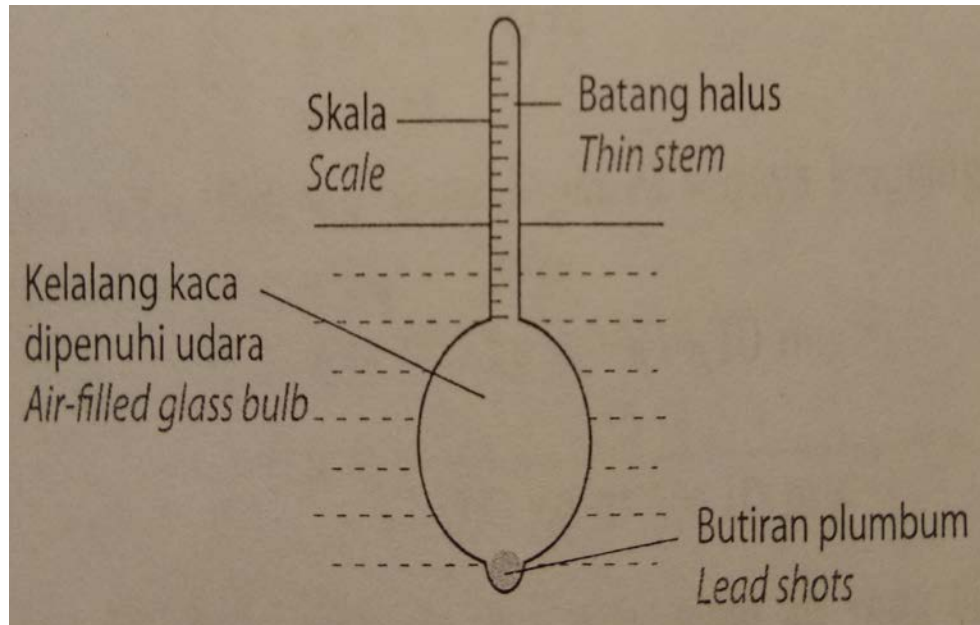


Figure 32. The application of hydrometer.

The hydrometer applies Idea A regarding the weight of liquid displaced, precisely the role of the density of a liquid, p , in the equation of Archimedes' principle, $F_B = pVg$. Aishah discussed the hydrometer with the students.

Aishah: A hydrometer is a tool to determine the density of liquid.

There are lead shots inside the hydrometer. We place the tool into a liquid. Then, we observe the position of the hydrometer on the scale. If the hydrometer floats higher, what do you think about the density of a liquid?

Student₁: The liquid has a higher density.

Aishah: What does it mean when the hydrometer floats lower?

Student₁: The liquid has a lower density.

Aishah: When the hydrometer floats higher, the density of a liquid is higher, and vice versa. OK. That is the function of a hydrometer.

[Code: AI-VOR-Aug 24-14]

Aishah told students that a hydrometer is used to determine the density of liquid. When the density of a liquid is high, the hydrometer will float higher, and vice versa. It is Idea A regarding the buoyant force and the weight of liquid displaced, specifically with regard to the variable of the density of a liquid, ρ , in the equation of $F_B = \rho Vg$.

Teaching episode 16: Closure, Idea A and Idea B. In the fourth lesson on August 24, 2015, Aishah first taught students Bernoulli's principle. When the instruction on Bernoulli's principle was completed, she summarized her teaching on Pascal's principle, Archimedes' principle, and Bernoulli's principle.

Aishah told students that:

Archimedes' principle is the hardest topic compared to Pascal's and Bernoulli's principle. The simplest principle is the Bernoulli's principle.

[Code: AI-VOR-Aug 24-2-8]

Aishah then summarized the final lesson on Archimedes' principle by asking students Idea B and Idea A of the principle. She used the questioning during whole class discussion activity. The representations used were VS and F.

Aishah: What does Archimedes' principle state?

Student₁: The buoyant force.

Aishah: OK. The buoyant force. It is equal to what?

Student₂: The weight of liquid displaced.

Aishah: Yes it is. Then? It is equal to what?

Student₃: $F_B = \rho Vg$.

Aishah: Yes, it is. Another one?

Student₄: The actual weight minuses the apparent weight.

Aishah: Right. What is the apparent weight?

Student₅: The weight of an object in a liquid.

Aishah: What about the actual weight?

Student₅: An object's weight in air.

Aishah: That's it.

Aishah recalled for students the lesson on Archimedes' principle. She asked students about Idea A where the buoyant force is equal to the weight of liquid displaced and the formula of Idea A which is $F_B = \rho Vg$. She then asked students about Idea B, which is about the loss of weight, the actual weight of an object and its weight in a liquid. Finally, Aishah finished the final episode by reminding students of the lesson on Bernoulli's principle.

Main characteristics of Aishah's teaching activities. Based on the whole teaching episodes, Aishah utilized four teaching activities: (1) lab work, (2) small group discussion after lab work, (3) lectures, and (4) questioning. Other activities like demonstrations and building physical models were not found.

Lab work. Aishah conducted this activity to confirm the relationship between the loss of weight of an object and the buoyant force (Idea B) and the relationship between the weight of liquid displaced with the buoyant force (Idea A) (episodes 2 and 3). She closely guided her students to investigate Idea B and Idea A by providing specific verbal instruction step-by-step. Her students just followed the instructions given to them and ran the lab work in groups. Students collected the data of the actual weight and apparent weight of a load, and calculated the difference of the two sets of data. The difference represents the value of the loss of weight of the object. Aishah then asked students to measure the weight of water displaced and students worked in groups to obtain that data. The students got the measure that was mostly close to the exact value of the weight of water displaced, which had to be equal to the buoyant force and the loss of weight of the object.

The activities of lab work were highly structured and mostly teacher-centered because the teacher closely directed students to run investigations of Idea A and Idea B. The students followed the teacher's instruction when running their investigations in groups.

Small group discussion after lab work. Aishah conducted this activity to discuss and verify the difference of measures of the actual weight of an object in air and its weight when it immersed in water or the apparent weight (Idea B), and the value of the weight of water displaced and the buoyant force (Idea A) (episodes 2 and 3). Aishah first asked students to discuss in groups the difference

of the two measures and she wanted each group to produce a single explanation to describe the difference. She then asked a representative from each group to write that group's explanation on the whiteboard in front of the class. When each group completed writing their explanation, Aishah started to verify each group's explanation. From six explanations available, she accepted four. The other two explanations were students' alternative concepts. Aishah used the same ways of conducting the small group discussion activity that were used for Idea A regarding the weight of water displaced. For this idea, Aishah just accepted one out of six explanations. Other explanations showed students' alternative concepts.

The activities of small group discussion after lab work were fairly student-centered because students worked in groups to come up with a single explanation regarding Idea A and Idea B. The teacher played a role in verifying the student groups' explanations.

Lectures. Aishah conducted lectures to describe the idea of flotation, which is that the weight of an object is equal to the buoyant force. Aishah gave lectures that explained the case of flotation where she mentioned that if object has a weight of 10 N, the buoyant force exerted on the object is also 10 N (episode 4). The lecturing activity was completely teacher-centered because Aishah described the concept without interactions with the students.

Questioning during whole class discussion. Aishah conducted questioning activities to:

- (1) Capture students' alternative concepts. Using question-and-answer activities, Aishah was able to identify students' concepts that were inaccurate. In episode 2, one of her students responded to her question about Idea B. One of her students did not give a right answer because she said that the buoyant force is equal to the actual weight of an object. Aishah corrected the student's answer by saying that the buoyant force is equal to the apparent loss of weight of an immersed object in a liquid. She used a written question from a commercial book when discussing Idea B with students. The pattern of questioning was IRF (Initiation-Response-Feedback) where Aishah gave a question to students, students gave an answer or answers, and she verified students' answers. This questioning technique was also used in episodes 9 and 11.
- (2) Add points to students' answers. In episode 3, Aishah asked students a question about Idea A. One of her students answered her question by saying that the buoyant force is equal to the loss of weight. Aishah accepted the student's answer because it is scientifically correct. However, Aishah added to the student's answer by saying that the buoyant force is also equal to the weight of liquid displaced (Idea A). The student's answer was Idea B. Aishah used a written question from a commercial book when discussing with students about Idea A. The pattern of questioning was IRF (Initiation-Response-Feedback) where Aishah asked students a question, students gave an answer or answers, and she added to students' answers.

- (3) Recognize students' correct answers. In episode 5, Aishah asked students a question about Idea D, immersion. One of her students answered the question by saying that an immersing object has a weight that is greater than the buoyant force. Aishah recognized her student's answer by telling the class that the answer was correct, and she rephrased the word of "greater than" as "larger than." Aishah used a written question from a commercial book when discussing Idea D with students. The pattern of questioning was IRF (Initiation-Response-Feedback) where Aishah posed a question to students, students gave an answer or answers, and she acknowledged her students' answers. She even praised her students when they gave right answers by saying "clever" and/or "good" to them in teaching episodes 6, 8 and 13. This questioning technique was also used in episodes 7, 10, 11, 12, 14, and 15.
- (4) Recall the overall learning. In the final episode, episode 16, Aishah asked students a question about the concept of Archimedes' principle. One of her students responded by saying that the buoyant force is equal to the weight of liquid displaced (Idea A). Aishah continued to ask students about the concept, and one student said that the buoyant force is equal to the apparent loss of weight of an object in a liquid (Idea B). Aishah expressed agreement about the students' answers. The questioning activity seemed to imitate the technique of IRF (Initiation-Response-Feedback) where Aishah

asked students a question, students gave an answer or answers, and she agreed with her students' answers.

The questioning activities were generally teacher-centered because the teacher initiated questions, then students gave answers, and the teacher gave feedback to students' responses. An IRF pattern was found: *Initiation* (teacher giving questions), *Response* (students providing answers), and *Feedback* (teacher giving reaction to students' response). The teacher primarily led the dialogue with students.

Main characteristics of Aishah's translation of representations in selected episodes. Selecting episodes and the way of presenting the sequences of representations for Aishah were done in the same ways as was done for Aminah. The selected episodes for Aishah were episodes 3, 6, 8, 9, 10, 12, 15, and 16.

In episode 3, Aishah translated modes of representations thus: $M_{a1} \rightarrow VS_{a1} \rightarrow VS_{a2} \rightarrow M_{a2} \rightarrow VS_{a3} \rightarrow VS_{s1} \rightarrow M_{a3} \rightarrow VS_{s2} \rightarrow WS_{s1} \rightarrow VS_{a4} \rightarrow VS_{s3} \rightarrow RLS_{a1} \rightarrow F_{a1} \rightarrow VS_{a5} \rightarrow VS_{s4} \rightarrow RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a6} \rightarrow VS_{s5}$. This translation is read as:

Aishah asked students to set up apparatuses for doing an investigation of the weight of liquid displaced ($M_{a1} \rightarrow VS_{a1}$). She verbally gave students specific instructions on how to run the investigation (VS_{a2}). Students ran the investigation in groups (M_{a2}). Then, Aishah asked students about the investigation of the phenomenon of the weight of liquid displaced and a student

answered her verbal questions. Aishah gave a response to the student's answer ($VS_{a3} \rightarrow VS_{s1}$). Aishah asked students to discuss in groups the relationship between the water displaced and the load, using the groups' findings of investigation ($M_{a3} \rightarrow VS_{s2}$). After that, Aishah asked each student group to write their answers on a board in front of the class and discussed students' answers with them ($WS_{s1} \rightarrow VS_{a4} \rightarrow VS_{s3}$). She added her explanations that one real-life situation of water displaced was when a person is swimming in a bathtub and the level of water increases; she also linked the swimming activity with the idea of the weight of water displaced, used formulae, and confirmed each group's answer ($RLS_{a1} \rightarrow F_{a1} \rightarrow VS_{a5} \rightarrow VS_{s4}$). Aishah continued her instruction by moving to discussing with students the weight of liquid displaced using a question in a book that contained a picture of water displaced and written quantitative questions ($RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a6} \rightarrow VS_{s5}$). The complete sequence of translation of representations was: $M_{a1} \rightarrow VS_{a1} \rightarrow VS_{a2} \rightarrow M_{a2} \rightarrow VS_{a3} \rightarrow VS_{s1} \rightarrow M_{a3} \rightarrow VS_{s2} \rightarrow WS_{s1} \rightarrow VS_{a4} \rightarrow VS_{s3} \rightarrow RLS_{a1} \rightarrow F_{a1} \rightarrow VS_{a5} \rightarrow VS_{s4} \rightarrow RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a6} \rightarrow VS_{s5}$.

In this episode, Aishah used the representations of M, VS, WS, RLS, F, and P. Other modes were not evident, namely T and G.

In episode 6, Aishah translated the representations as: $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$. This translation is read as:

From a written quantitative question regarding the apparent loss of weight of an immersed object in water and the weight of water displaced in an actual setting, Aishah discussed the question with the whole class using dialogues with students ($RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1}$). Students were required to apply the formula of Archimedes' principle regarding the apparent loss of weight of an immersed object (Idea B), $F_B = W_1 - W_2$ to solve the calculation question (F_{a1}). Aishah continued to discuss with the class the question regarding the apparent loss of weight of an immersed object using dialogues ($VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3}$). Then, she moved to discussing the next question about the weight of water displaced where students needed to apply the formula of $F = Vpg$ (F_{b1}). Aishah dialogued with students about the question and finally asked students to write all of their solutions ($VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$). Thus, the sequence of translation was $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$.

In this episode, Aishah used the modes of RLS, WS, VS, and F. Modes of P, T, G, and M were not evident.

In episode 8, Aishah used the sequence of translation of $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$. This translation is read as:

From a written quantitative question regarding the apparent loss of weight of an immersed object in water and the weight of water displaced in an actual setting, Aishah discussed the question with the whole class using dialogues with students ($RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1}$). Students needed to use the formula of Archimedes' principle regarding the apparent loss of weight of an immersed object (Idea B), $F_B = W_1 - W_2$ to solve the question (F_{a1}). Aishah continued to discuss with the class the question regarding the apparent loss of weight of an immersed object using the dialogues ($VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3}$). Then, she moved to discussing the next question about the weight of water displaced where students needed to apply the formula of $F = \rho Vg$ (F_{b1}). Aishah made dialogues with students about the question and finally asked students to write all of their solutions ($VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$).

Thus, the sequence of translation was $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$.

In this episode, Aishah used the modes of RLS, WS, VS, and F. Modes of P, T, G, and M were not evident. The sequence of translation in this episode was similar with episode 6.

In episode 9, the sequence of translation was $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$. This translation means:

From a written quantitative question regarding the weight of liquid displaced and flotation that contains a picture of a floating test tube, Aishah discussed the question with the whole class using dialogues with students ($RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1}$).

Students needed to be able to use the formula of the weight of liquid displaced to solve the first question (F_{a1}). Aishah continued to discuss with the class the question regarding the weight of liquid displaced using the dialogues ($VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3}$).

Then, she moved to discussing the next question about flotation where students needed to apply the formula of $F = mg$ (F_{b1}).

Aishah dialogued with students about the question and finally asked students to write all of their solutions ($VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$). Thus, the full translation was $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$.

In this episode, Aishah used the modes of RLS, P, WS, VS, and F. Modes of T, G, and M were not used. The translation was quite similar to that of episodes 6 and 8, and differed only in the use of a pictorial representation, P.

In episode 10, Aishah used the sequence of translation of $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$. No description is provided here because the pattern of translation was similar to those of episodes 6 and 8. Modes of P, T, G, and M were not evident, but other modes were used, namely RLS, WS, VS, and F.

In episode 12, the sequence of translation was $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{s1}$. The translation is read as:

From a picture that contained a diagram of a ship and its explanations, Aishah made a dialogue with students about the real-life situation of Archimedes' principle ($RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1}$). She then asked students to write their explanations in the book about the idea of the weight of liquid displaced and flotation applied by the ship (WS_{s1}). Thus, the translation was $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{s1}$.

The translation was quite simple. The modes used were RLS, P, WS, and VS. Other modes, G, T, P, and M, were not apparent.

In episode 15, the translation sequence was $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{s1}$. This translation was similar to that of episode 12; thus, no description is provided here.

In episode 16, the sequence of translation was $VS_{a1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4}$. It is read as:

Aishah explained to students that Archimedes' principle is a more difficult topic than other topics of Pascal's and Bernoulli's principles (VS_{a1}) and made dialogues with students about Idea A and Idea B where she asked students about the formula of Archimedes' principle, $F = V\rho g$, related to Idea A, during the dialogue ($F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2}$). She then made a dialogue about another formula, $F = W_1 - W_2$, which is related to Idea B ($F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4}$). Thus, the translation was $VS_{a1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4}$.

The translation only involved the modes of VS and F. Other modes were not used, T, G, P, M, WS, and RLS.

Overall, Aishah's uses of representations indicate that verbal symbols (VS) and written symbols (WS) surrounded real-life situation (RLS) and formula (F) representations in the selected episodes. VS primarily came from questioning activities or dialogues while WS came from students' written answers. RLS and F representations were mainly portrayed through pictures (P), VS, and WS. M representations were used in the earlier episode, episode 3. Nonetheless, representations of tables (T) and graphs (G) were not used in any of the episodes.

Amplifiers and filters. This section describes Aishah's amplifiers and filters of teaching that included instructional goals, reasons for adopting particular

teaching activities, and contextual and/or personal factors that informed her instruction.

Contextual amplifiers. There were two kinds of contextual amplifiers: (1) national contextual amplifiers and (2) school contextual amplifiers. The first national contextual amplifier was the requirement to complete teaching of the national syllabus. Aishah needed to finish teaching the physics syllabus on time. If not, students would not be well prepared for school exams and the national exam. She stated that:

I have a timeframe to finish the physics syllabus because students will sit for examinations at the school level. If I always use the inquiry approach, my instructional time will drag, and the syllabus will not be completed.

[Code: AI-PREIN-June 29-49]

Completing the national syllabus, in turn, was a critical mission of her teaching.

The second national contextual amplifier was the recommendation of a particular order for teaching physics topics set by the national curriculum, and instructional objectives. Aishah recognized that the national physics curriculum helped her get the information in the proper sequence of physics topics needed to be taught to students. She realized that the topic of pressure must be taught earlier before teaching other advanced topics like Archimedes' principle because the pressure concept is the fundamental idea of the principle of Archimedes [Code: AI-PREIN-June 29-34 & AI-POSTIN1-Aug 30-6]. The national curriculum

specifically suggests instructional objectives for each physics topic and Aishah followed the objectives provided [Code: AI-PREIN-June 29-35].

The third national contextual amplifier was the recommendations of teaching activities. The national curriculum suggests teachers use inquiry-based learning, specifically lab work, discussion, and physical model. Aishah adopted the activities of lab work and discussion [Code: AI-PREIN-June 29-29], but did not adopt models.

The fourth amplifier was both a national and school contextual amplifier: to prepare students for taking the national exam and school exams. School exams followed the format of the national exam questions. Aishah stated that the aim of preparing students for taking exams was the major purpose of her teaching. She said that:

My primary goal of teaching is to ensure students can score in exams. Exam questions are set using the instructional objectives given by the national curriculum. For school exams, we usually focus on Paper 2 of the national exam questions.

[Code: AI-PREIN-June 29-4, AI-POSTIN1-Aug 30-17, & AI-
POSTIN1-Aug 30-26]

Another type of school contextual amplifier was Aishah's school's target for academic achievement. These are school amplifiers. She regarded her school's aim as the significant factor of her instructional goal. She mentioned that her school set a high target on academic achievement. She said that:

I wanted students to be able to score well in physics for examinations and tests because this school highly values examination and test results and this school intends for students to achieve a high standard of academic achievement.

[Code: AI-PREIN-June 29-4, AI-PREIN-June 29-42, AI-PREIN-June 29-43, & AI-POSTIN1-Aug 30-38]

Aishah felt that the high target set forth by her school forced her to place greater efforts on ensuring students can get high scores in exams and tests. She collaborated with colleagues to meet the school's target. She set a goal for every student to be able to successfully pass physics and not fail. She used students' academic achievements as the indicator of her teaching performance. She regularly reflected on what she taught and the ways she taught to ensure that students got the best instruction from her [Code: AI-PREIN-June 29-42].

Another school contextual amplifier was availability of laboratory equipment. Aishah's school provided lab supplies that allowed her to conduct lab work [Code: AI-DOCPH-Aug 17-1 and AI-DOCPH-Aug 17-2].

Contextual filters. One contextual filter identified was class size. It was a school filter. Aishah explained:

I cannot always adopt the inquiry approach because the ratio of students to teachers is still too big. In my class, I have 30 students. It is a huge number. That is the reason why I feel that it is hard to conduct inquiry-based learning. I need to see each student's work,

but it is not possible because many students are in the lab. It consumes a lot of time. If I had 20 to 25 students, it might be possible to use inquiry consistently.

[Code: AI-PREIN-June 29-32 & AI-PREIN-June 29-33]

The big class size made it hard for Aishah to facilitate students' activities, especially when conducting inquiry-based learning. A large number of students made it impossible for her to reach every student. She hoped that the class size would be around 20 to 25 students as the maximum number.

The second contextual filter was Aishah's time constraint. It was also a school filter. Her time for preparing and implementing instruction was limited due to heavy workloads. She revealed that:

The workload of teachers needs to be revised. It is important to allow teachers to focus entirely on teaching and learning. If teachers are burdened with too much bookkeeping work like managing files and documents, teachers will be stressed. Teachers need to search for materials for teaching, do other kinds of work, and fill out forms and so on. It creates a challenge to implement instructional plans.

[Code: AI-POSTIN2-Sept 2-44]

Aishah needed to do other works besides teaching, which made her rushed to prepare and finish teaching the national syllabus. Those clerical tasks were not particularly related to teaching. However, they significantly reduced her time for preparing and implementing instruction.

Personal amplifiers. Aishah indicated that she wanted students to be able to apply physics knowledge to their daily lives. She desired for students to be able to explain natural phenomena or applications in real-world settings using physics knowledge learned in the instruction. Aishah revealed that the main reason she wanted students to be able to do that was the closeness of physics in human life. She said that:

Physics is everything in our environments. That is physics. If students learn physics, they actually learn what all is in their daily lives. However, they might not know that a phenomenon is related to physics. That was the reason why I feel I must connect physics with students' real world contexts. Physics is quite a bit more concrete than chemistry or biology because physical phenomena can be observed.

[Code: AI-POSTIN2-Sept 2-5]

Based on what she said, physics is a kind of knowledge that is related closely to real-world applications or phenomena. During her instruction, she taught students about applications of Archimedes' principle like submarines, boats, ships, and hot air balloons to make connections between physics and students' real lives. The teaching episodes 11, 12, 13, and 14 showed how Aishah taught students those applications (see Figures 26, 27, 28, 29, and 30).

The following paragraphs lay out Aishah's reasons for using particular teaching activities.

Questioning during whole class discussion. Aishah spent a significant amount of time adopting this activity when teaching Archimedes' Principle, around 147 minutes out of 190 minutes. Aishah used this activity in all teaching episodes, except episode 1 and 4. These exceptions on just two episodes were the evidence that she consistently used the questioning activity throughout her teaching on the Archimedes' principle. In fact, she used the activity in teaching all ideas, Idea A to Idea D. She relied much on the book that she purchased, and the book strongly guided her questioning activities. She primarily used the book to discuss written questions on Archimedes' principle with students.

Aishah mentioned one reason for using the questioning activity. She wanted to know students' existing knowledge and alternative conceptions in ideas of Archimedes' principle. She said that:

When I engage in questions and answers with students, I can know what they're thinking. I am OK with accepting any ideas even though the ideas might be inaccurate. I need to accept them (the ideas) first so that I can verify them later. When I ask students some questions, I can then develop their existing ideas into a particular concept.

[Code: AI-POSTIN2-Sept 2-6]

Aishah indeed verified her students' alternative conceptions when using the questioning activity during instruction. For instance, she rejected two conceptions regarding Idea B, the loss of weight of an object in a liquid. It

happened in the teaching episode 2. Another example of how Aishah used the questioning during whole class discussion activity was in the teaching episode 8. Using a quantitative question from the book (Figure 24), she taught students Idea B and Idea A. She engaged in a dialogue with students to learn their ideas about the questions. The dialogue shows that Aishah used the questioning activity to discover students' ideas about the question. It was clear that students understood well the quantitative question in Figure 24 as demonstrated in the teaching episode 8, which emphasized Idea B and Idea A. Students provided correct responses to Aishah's questions. Therefore, it was true that Aishah's use of the questioning activity can identify right conceptions of students as well as their alternative conceptions.

Laboratory work. Aishah spent nearly 33 minutes for teaching using the lab work activity. She used this activity in the teaching episodes 2 and 3, and particularly in teaching Idea B and Idea A. She guided students to carry out the lab work regarding Idea B and A, step-by-step. It was evident that Aishah used this activity during the early episodes of teaching.

Aishah stated several reasons for using the lab work activity. The first reason was the activity was useful for teaching a complex idea like Archimedes' principle. She said that:

The lab work was useful for teaching Archimedes' principle. The activity could help students understood the complex ideas like Archimedes. To me, Archimedes' principle was the hardest topic

in the unit of Force and Pressure because it consists of a lot of formulae. I conducted three investigations on Archimedes' principle. I wanted students to be able to connect the formulae of Archimedes' principle with those three investigations. Those three formulae verify that the buoyant force is equal to the loss of weight, is equal to the weight of liquid displaced, and is equal to pVg .

[Code: AI-POSTIN2-Sept 2-25]

During the teaching episode 16, Aishah told students that:

Archimedes' principle is the hardest topic compared to Pascal's and Bernoulli's principle. The simplest principle is Bernoulli's principle.

[Code: AI-VOR-Aug 24-2-8]

Aishah said to her students that the topic of Archimedes' principle was difficult compared to other principles like Pascal's and Bernoulli's principle. Hence, Aishah words during the teaching episode 16 were consistent with her words during the interviews. She conducted lab experiments to help students acquire the ideas of Archimedes' principle, particularly Idea B and Idea A regarding the loss of weight and the weight of liquid displaced (in the teaching episodes 2 and 3).

The second reason was the lab work activity allowed students to engage with a manipulative type of learning through measurement of variables. Aishah said that:

When using the lab work activity, students can learn Archimedes' principle through hands-on experience. They can see the ideas of Archimedes concretely. They can measure the weight of an object in air and its weight in a liquid. They can figure out the measurement by themselves. If I just talked to them, they might not believe what I was saying. They measured the variables of Archimedes themselves. Then, they could get data from their investigations and connected their readings with the idea of buoyant force.

[Code: AI-POSTIN1-Aug 30-36]

The activity of lab work can provide students with concrete experience in using lab equipment and in collecting data or readings of variables. Hence, students can use their data to connect with the ideas of Archimedes' principle.

The third reason for using the lab work activity was to prepare students for taking Paper 3 in the national exam. She said that:

Whatever I teach will be asked in the national exam, like Paper 3. The third paper particularly asks students to plan an investigation of a particular physical phenomenon. They should know how to design an investigation and systematically write procedures. The investigation that I conducted in the laboratory is to prepare students for answering questions in Paper 3.

[Code: AI-PREIN-June 29-40 & AI-PREIN-June 29-41]

Aishah's words were consistent with one of the contextual amplifiers – preparing students for the national exam (see the section of contextual amplifiers). The national exam consists of three papers, Paper 1, Paper 2, and Paper 3. She conducted investigations of Archimedes' principle because she wanted students to get familiar with the requirement of Paper 3 in the national exam which specifically asks students to plan an investigation of a physical phenomenon.

Small group discussion after lab work. Aishah spent a small portion of time using this activity, around 8 minutes. She used this activity in the teaching episodes 2 and 3 and specifically for teaching Idea B and Idea A. She conducted the small group discussion activities when each lab work was completed. That is why the teaching episodes were the same for the lab work and the small group discussion activities.

Aishah indicated one reason for using the small group discussion after lab work activity. The reason was the activity allowed students to exchange ideas among group members. She briefly mentioned this during the post-teaching interview, and she also explained why she did not use this activity very much:

I conducted the small group discussion activity because it allowed students to actively participate in group work, especially in small groups as I did. It was better to use small groups than big groups.

They can exchange roles and ideas among group members.

However, I cannot always implement this activity due to time constraints. Students took much time for discussing questions

provided to them because the answers were not available in the textbook. They argued among themselves about the right answer because the textbook's information was incomplete.

[Code: AI-POSTIN1-Aug 30-25 & AI-POSTIN2-Sept 2-23]

Aishah did not spend much time using the activity of small group discussion. Her students tended to use a significant amount of time for searching answers to the problems given. During the teaching episodes 2 and 3, she used this activity with a small allocation of time, about 8 minutes in total. The reason she stated for using the activity to a limited extent was that she thought her time was constrained. She also did not utilize this activity when conducting the discussion of quantitative questions in the teaching episodes 6, 7, 8, 9, and 10. She, instead, used the activity of questioning during whole class discussion.

Lectures. Aishah spent a small portion of time using this activity, around 2 minutes. She used this activity in the teaching episode 4 and specifically for teaching Idea C regarding flotation. She gave a brief lecture during episode 4.

Aishah mentioned one reason for using the lecture activity. She said that it allowed her to finish teaching on time, but she realized that it was not suitable because it created a passive learning environment for students. She said that:

If I used the chalk-and-talk (the lecture activity), I could finish teaching the syllabus on time. I just need to explain to students and just ask them a little, so I can finish teaching what I need to deliver to them. However, I knew that the activity created a passive

learning environment because students just accepted what I said. I could guarantee that students will not understand 100 percent of my teaching if I used this activity often. They might just gain around 50 to 60 percent in understanding.

[Code: AI-PREIN-June 29-23 & AI-PREIN-June 29-39]

Aishah did not use this activity very much when teaching the Archimedes' principle. She just briefly lectured students on Idea C in episode 4. She knew that the lecture activity was not suitable because it made students passive in learning.

Personal filters. One personal filter came from Aishah's choice to use specific curricular materials like the commercial book for her teaching. She greatly relied on the book purchased from a commercial company. Hence, this curricular material shaped her contents of teaching and had guided her instruction in certain ways. For example, she used the written questions in the book when conducting questioning activities, particularly when teaching students quantitative problems on Archimedes' principle.

Case III: Ali

Ali's background. Ali received a master's degree in physics education in 2012 from a public research university in Malaysia. He also had a bachelor's degree in the same major from the same university in 2008. Ali has been teaching physics for more than seven years, since 2008, at the upper secondary school level (Grade 11 and 12). He has taught students of a high cognitive level because his school is one of the top schools in the district, comprised of students with

excellent academic performance. His school's location was in an urban area in Johor, Malaysia. Throughout his service as a physics teacher, he has joined professional development programs like conducting laboratory works and making reports of experiments.

Ali's physics class. Physics is a compulsory subject for students who choose to take the science stream. Ali taught physics for two 80-minute periods in a week. He mixed the native language, Malay, and English for teaching physics. Nevertheless, English is the primary verbal language. Curricular materials like slides and notes were also in English, but written questions were available in the two languages.

Ali taught Archimedes' principle in three lessons on July 22, July 23, and July 29, 2015. In the first lesson, he introduced students to Archimedes' principle. In the second lesson, he spent part of the lesson for teaching Archimedes' principle. He taught Bernoulli's principle in the same lesson. In the final lesson, he continued teaching Bernoulli's principle and then moved to teaching Archimedes' principle.

Ali used teaching notes that he made himself for teaching Archimedes' principle. He also utilized a set of written questions obtained from a commercial book published by a company. He purchased the book. Those written questions imitated the national exam questions. Ali employed two types of questions, mathematical and conceptual. Moreover, he used slides he made by himself. These curricular materials align with the specifications of the national curriculum.

Classroom practices. Ali put forth three instructional objectives indicating what students should be able to do: (1) state the principle, (2) describe applications of the principle, and (3) solve problems regarding the principle. These objectives came from the national curriculum [Code: AL-DOCLP-July 22-1, AL-DOCLP-July 22-2, AL-DOCLP-July 22-5, AL-DOCPH-July 22-8, & AL-DOCPH-July 22-9].

The main ideas Ali taught were:

Idea A: The weight of liquid displaced by an object is equal to the buoyant force.

Idea B: The weight loss of an object is equal to the buoyant force.

Idea C: In a flotation case, the weight of an object is equal to the weight of the fluid displaced by the object.

Idea D: In an immersion case, the volume of the immersed object is equal to the volume of water displaced.

All ideas were found in the national curriculum.

Overall, Ali adopted two activities for teaching the main ideas of Archimedes' principle: (1) questioning during whole class discussion and (2) lectures. In total, he spent 125 minutes for teaching the principle in three lessons. The questioning activity was used nearly 112 minutes while the lecture activity was used around 13 minutes. Ali's teaching is described in 13 episodes.

Teaching episode 1: Introduction. In the first lesson, Ali introduced students to Idea A of Archimedes' principle – the weight of liquid displaced by an

object is equal to the buoyant force (Objective 1). He used the lecture and questioning during whole class discussion activities. Representations used were verbal symbols (VS), written symbols (WS), a picture (P), and a real-life situation (RLS). Other representations were not evident, specifically graphs (G), tables (T), manipulatives (M), and formulae (F).

Ali initially lectured about Idea A.

Archimedes' principle states that the upward buoyant force on a submerged object is equal to the weight of the liquid that is displaced by the object.

[Code: AL-VOR-July 22-1 & AL-VOR-July 22-2]

He literally read the slide that showed Idea A of Archimedes' principle. Figure 33 shows the slide.

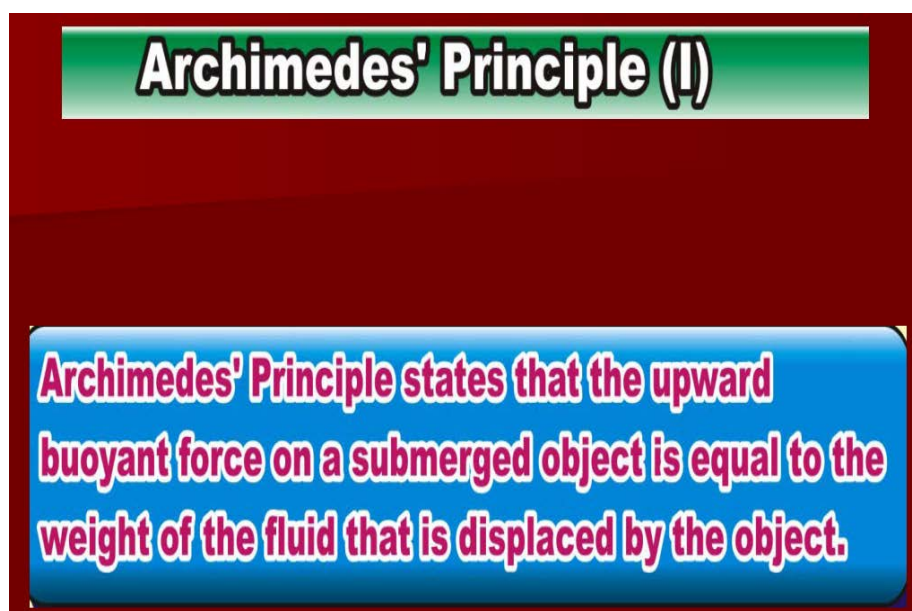


Figure 33. Idea A of Archimedes' principle.

[Code: AL-DOCSL-July 22-2]

Ali continued teaching Idea A using the questioning during whole class discussion activity. He engaged in dialogue with students and used a slide (Figure 34) to assist the dialogue.

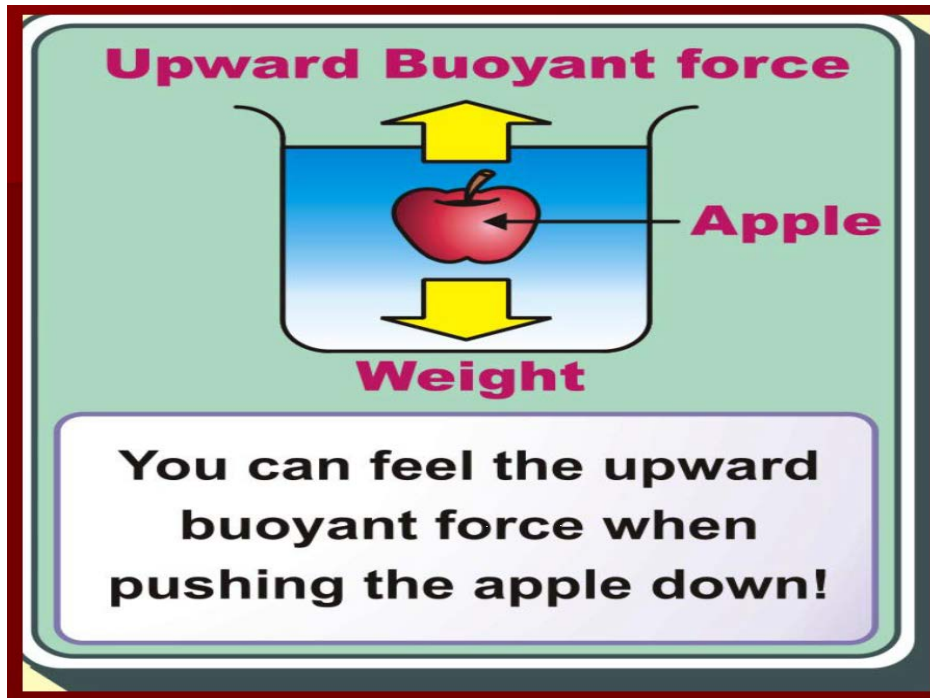


Figure 34. The weight of liquid displaced.

[Code: AL-DOCSL-July 22-1]

Ali: Can you understand the statement in the first slide (Figure 33)?

Student₁: No.

Ali: OK. Let's say I change the statement into a diagram (Figure 34). I place an apple into a beaker. There are two forces acting on the apple. The first is the weight, W . Another is the buoyant force. The apple seems to float. Before I place the apple into water, there

is just water. Then, if we place the apple or an object, what happens to the water?

Student₂: It is pushed.

Ali: OK. If the beaker is very small, the water will flow out or be displaced. The water is displaced. We call it “displaced water.” If we measure the displaced water, then the weight of the water displaced is equal to what?

Student₂: The apple’s weight.

Ali: It is equal to the buoyant force.

Student₃: Ooo.

Ali: You can feel the upward buoyant force when pushing the apple down into the water. The first idea of Archimedes’ principle is the weight of water displaced is equal to the buoyant force.

[Code: AL-VOR-July 22-5]

Ali tried to build his students’ understanding regarding the weight of liquid displaced by giving an example of a floating apple. He asked students about the magnitude of water displaced, and a student said that the magnitude was equal to the apple’s weight. Ali corrected his student’s idea by saying that the magnitude of water displaced by the apple is equal to the buoyant force.

Teaching episode 2: Idea A. In the same lesson, Ali continued teaching Idea A regarding the weight of liquid displaced (Objective 1). He used the questioning during whole class discussion activity. Representations used were

VS, WS, and RLS, while other representations were not evident, namely G, T, M, F, and P.

Ali used a slide to continue to teach students Idea A. Figure 35 shows the diagram. He engaged in dialogue with students about the slides.

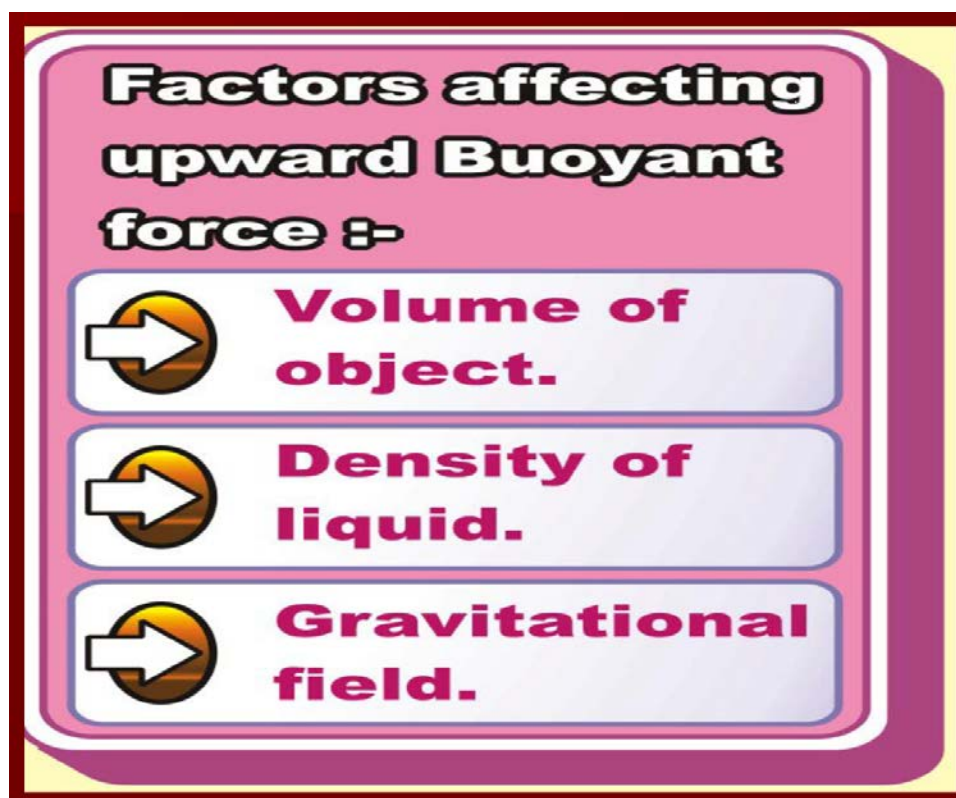


Figure 35. Factors influencing the buoyant force.

[Code: AL-DOCSL-July 22-4]

Ali: See the diagram (Figure 35). What are factors that affect the upward buoyant force?

Student₁: Density.

Ali: Indeed.

Student₂: The volume of an object.

Ali: Yes. You just mentioned the density of liquid. If you use different types of liquids that means you have different densities. For instance, we can compare water and seawater. If we place the same apple into two those liquids, what difference can you note as to the level of the apple?

Student₁: The apple floats higher in seawater than fresh water.

Ali: Yes, it does. It floats higher in seawater than fresh water. Then, see the volume of an object. The bigger the object, the bigger the buoyant force because its weight sustains the volume, right? The weight of the apples is equal to the buoyant force. We will see this idea after this. Hence, factors affecting the buoyant force are the volume of an object, the density of a liquid, and the gravitational acceleration (Figure 35).

[Code: AL-VOR-July 22-11]

Ali's student gave a correct answer when saying that an apple floats higher in seawater than in fresh water due to a bigger density of the seawater compared to fresh water.

Teaching episode 3: Idea C. In the same lesson, Ali moved to teaching Idea C regarding flotation – the weight of an object is equal to the weight of the fluid displaced by the object (Objective 1). He used the lecture and questioning during whole class discussion activity. Representations used were VS, WS, P, RLS, and F, while G, T, and M representations were not used.

Ali engaged in dialogue with the students. He used a slide to assist the dialogue. Figure 36 shows the slide.

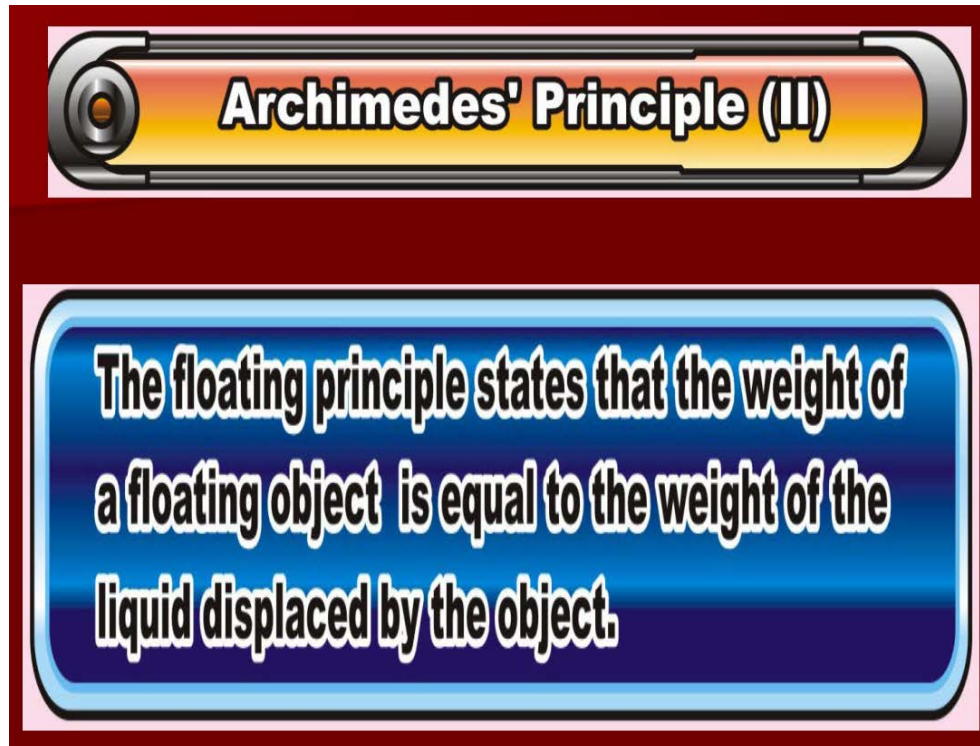


Figure 36. Idea C regarding flotation.

Ali first lectured on the idea of flotation (Idea C) by stating the fundamental idea of flotation.

The flotation principle states that the weight of the floating object is equal to the weight of liquid displaced by the object.

[Code: AL-VOR-July 22-14]

He directly read the slide in Figure 36.

He continued using the lecture activity and used a slide to assist his explanations. Figure 37 shows the slide.

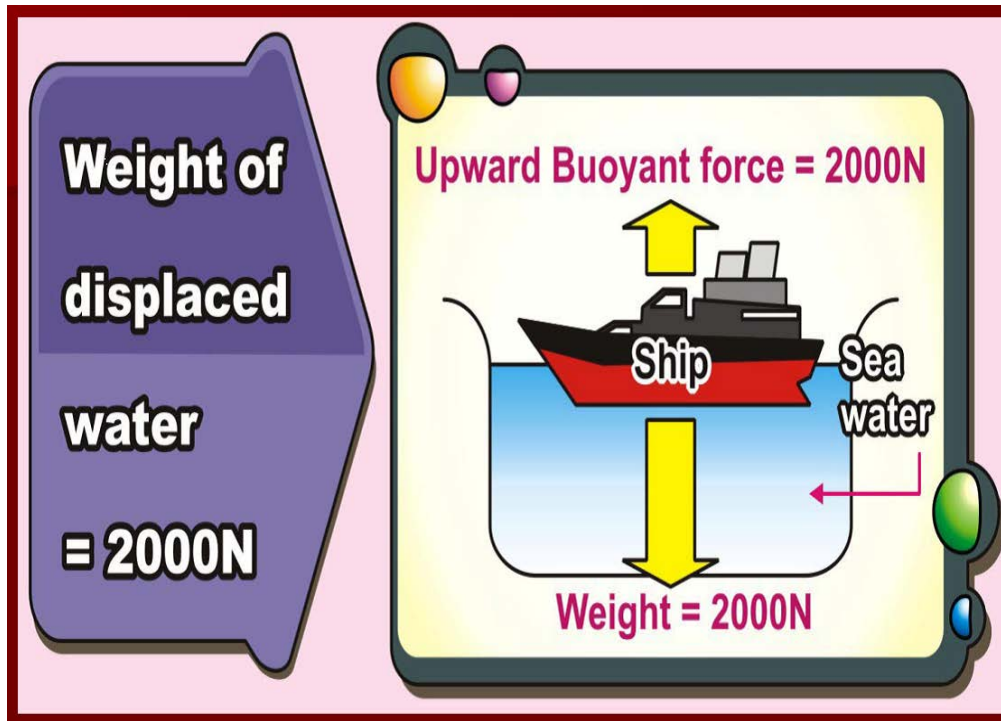


Figure 37. Idea C regarding flotation applied to a ship.

Ali gave the lecture.

If I change the statement (in Figure 36) into a diagram (Figure 37), the ship is static and is floating. If the ship is moving down, we can say that its weight is greater than the buoyant force. Or, if the ship is moving up, we can say that the buoyant force is greater than the weight of the ship. However, this ship (Figure 37) is floating. Its weight is 2000 N. So, the buoyant force is also 2000 N. If we measure the weight of water displaced, the magnitude will also be 2000 N.

[Code: AL-VOR-July 22-15]

The slide in Figure 37 shows the picture of a floating ship. Ali taught students that the weight of an object is equal to the buoyant force in the case of flotation (Idea C). He used an example of the ship having the weight of 2000 N. Hence the buoyant force exerted on the ship is also 2000 N and the weight of the liquid displaced is 2000 N too.

A student asked Ali a question regarding the flotation and the weight of liquid displaced.

Student₁: Teacher, what is the difference between this case (flotation) and the previous one (the weight of liquid displaced)?

Ali: I do not want to combine these two ideas. This case is flotation. The previous case is the weight of liquid displaced. If we simplify the flotation formula, it becomes the buoyant force is equal to the weight of an object and is equal to the weight of liquid displaced. The symbol of the buoyant force is F_B . Then it is equal to the weight of an object, W . What is the formula of weight?

Student₁: $W = mg$.

Ali: Yes, it is. $W = mg$. So, the $F_B = mg$. Then, we replace mass, m , with ρV (the formula of density, $\rho = m/V$). Finally, we get $F_B = \rho Vg$. The formula is not limited to $F_B = mg$. You can also use the formula of $F_B = \rho Vg$. If a question does not provide the value of mass (m) but gives the value of the volume (V) and the density (ρ), you can still calculate the buoyant force.

[Code: AL-VOR-July 22-14]

Ali clarified the difference between Idea A and Idea C. He explained that Idea C uses the formula of $F_B = mg$ where the F_B is the buoyant force while mg is the weight of an object. Meanwhile, Idea A is the whole idea of Archimedes' principle where the buoyant force is equal to the weight of liquid displaced or $F_B = \rho Vg$. Ali wanted students to be able to use the formula of density, $\rho = m/V$ when using the formula of $F_B = mg$ and $F_B = \rho Vg$.

Teaching episode 4: Idea C and Idea D. In the same lesson, Ali continued teaching Idea C (flotation), but at the same time, he combined it with Idea D (immersion) (Objective 1). He also taught students the application of flotation, a ship (Objective 2). Ali used the questioning during whole class discussion activity. Representations used were VS, WS, P, and RLS.

Figure 38 and Figure 39 shows Idea C and Idea D. Ali used the slide to teach students both ideas.

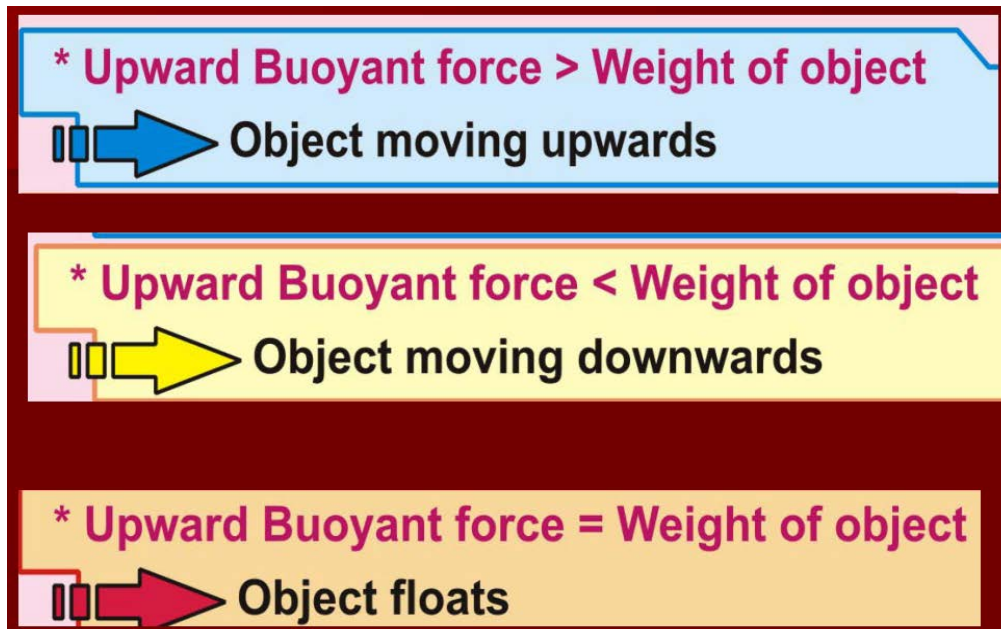


Figure 38. Ideas of flotation and immersion.

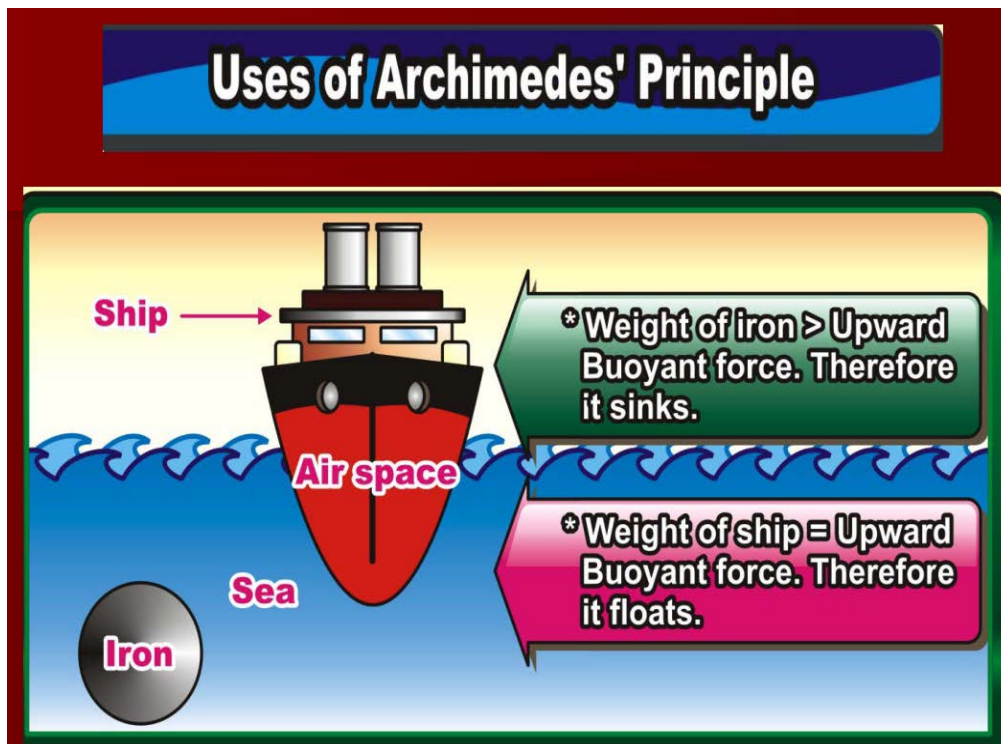


Figure 39. Applications of flotation and immersion.

Ali initiated a dialogue regarding Figure 38 and Figure 39.

Ali: See the slide (Figure 38). Upward buoyant force is greater than the weight of an object. In this case, the object is moving upwards. Then, upward buoyant force is smaller than the weight of an object. In this situation, the object is sinking. The upward buoyant force is equal to the weight of an object. In this case, the object is floating. It means the object is static. It is not moving. For the first case, the object is moving upwards. If you stand on a ship or a boat, the boat is floating, right? Then, if you take out a coin and throw it into the water, why does the coin sink, although the ship is floating?

Student₁: The density.

Ali: Why?

Student₁: The coin is solid.

Ali: Yes, it is. And if you are on a cruise, a big ship, and then you throw out a coin, the coin sinks but the big ship floats. Why?

Please think about it.

Student₃: There is air.

Ali: What kind of air?

Student₃: Ballast tank.

Ali: Normally, a ship does not have a ballast tank. A submarine uses it. Your friend said there is air. That's correct. The coin is solid, right? If we compare both objects, the bottom side of a ship

has air space. We can compare a coin with an iron (shown in Figure 39). Please make sure you are not confused with flotation and immersion. The weight of the ship is equal to the buoyant force (Figure 39). They are equal. Meanwhile, the weight of the iron is greater than the buoyant force (Figure 39), so it sinks. The object moves downwards (Figure 38).

[Code: AL-VOR-July 22-18 & AL-VOR-July 22-19]

Ali combined Idea C (flotation) and Idea D (immersion) in this episode. He taught students that the ship floats because its weight is equal to the buoyant force (Figure 39). Meanwhile, the iron in Figure 39 submerges because its weight is greater than the buoyant force. Ali used Figure 39 that puts together the idea of flotation (Idea C) and immersion (Idea D).

In the same episode, Ali continued teaching students Idea C and Idea D. He taught students about an application of these ideas, namely the case of a submarine (Objective 2). He used the questioning during whole class discussion activity. Figure 40 show the application of Idea D. Ali used the slide when teaching this idea.

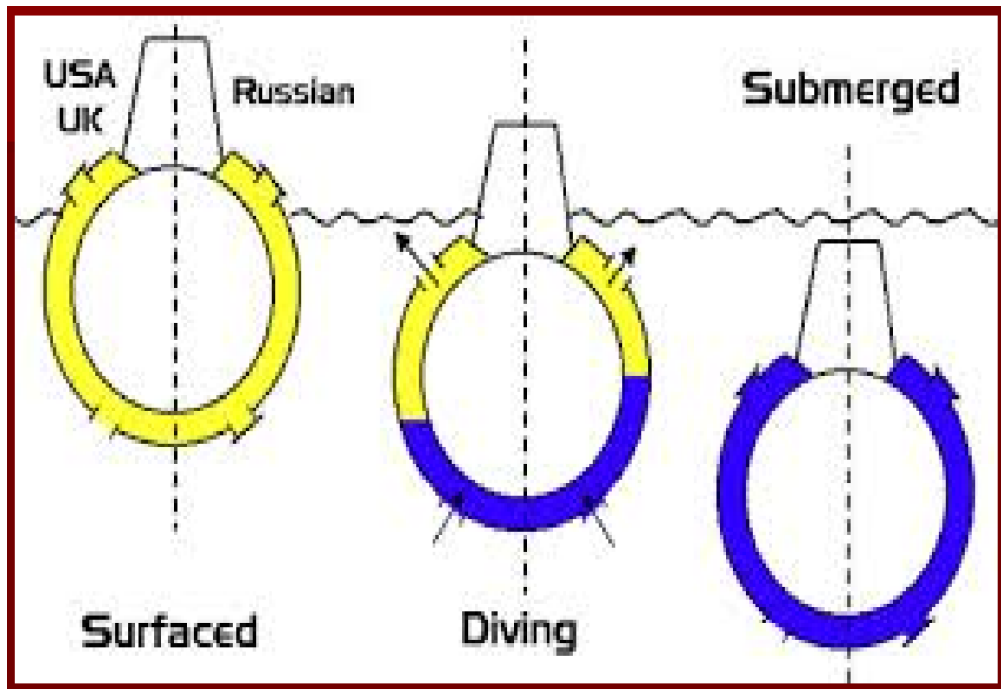


Figure 40. The application of immersion, a submarine's ballast tank.

Ali engaged in dialogue with students about the application of Idea C and Idea D, a submarine and its ballast tank.

Ali: See here (Figure 40). A submarine. Is there any volunteer to explain why a submarine can sink and float?

Student₁: It absorbs heat.

Ali: Absorbs heat? If we see the cross-section of a submarine, there is a space for ballast tanks (Figure 40). The blue color is the water that is filled into the ballast tanks. When the water is filled partially, it floats. However, when the tanks are filled fully with the water, the submarine submerges. How can they remove or insert the water?

Student₂: With submarine pumps.

Ali: Yes, of course, pumps. It uses a pump. If the submarine is supposed to submerge deeper, seawater will be pumped into the ballast tank. Then, what happens to the ballast tank?

Student₃: It becomes full.

Ali: OK. The weight of the submarine increases, so its density also increases. The weight of the submarine is greater than the buoyant force. That's why it submerges. You must be able to explain this as I said it. If the submarine pumps out the water that means the weight decreases. Then, the density of the submarine decreases. Thus, the buoyant force is greater than the density of the submarine (flotation).

[Code: AL-VOR-July 22-21]

During the dialogue, Ali taught students Idea C (flotation) and Idea D (immersion) through the same RLS representation, a submarine. The case of a submarine applies both ideas, Idea C and Idea D. Ali states that a submarine needs to pump in seawater in order to submerge. The ballast tanks must be filled fully. When more water is filled into the tanks, the density of the submarine increases, and thus increases the weight. Then, the submarine submerges when its weight is greater than the buoyant force exerted on the submarine. If the submarine wants to float, it must pump out water in the ballast tank. Then, the density of the

submarine decreases, and its weight decreases. Hence, the weight of the submarine is less than the buoyant force, and it floats on the sea.

Teaching episode 5: Idea C. In the same lesson, Ali taught students Idea C regarding flotation. He used the application of hot air balloons for teaching the idea (Objective 2). The questioning during whole class discussion activity was used. Ali used the representations of VS, WS, P, and RLS.

Figure 41 shows the hot air balloons.

AIR BALLOONS

- The hot air balloon can be made to float in the air.
- The light, hot air inside the balloon displaces the cold air to produce a buoyancy force use to lift the balloon.
- Balloons that are filled with a light gas can also be made to float or rise in the air.

Upward buoyant force > Weight of balloon.

Air balloon

Upward buoyant force

Weight

Figure 41. The application of flotation, hot air balloons.

Ali used the questioning during whole class discussion activity for teaching the application Idea C, hot air balloons.

Ali: How does a hot air balloon work? The buoyant force must be greater than the weight of the balloon. How does the balloon expand?

Student₁: It uses fire.

Ali: Yes, it does. It uses fire. It will produce hot air so the hot air will fill the balloon. This is related to the density. Is the density of hot air less dense or denser?

Student₂: Less dense.

Ali: Less dense, right? When it is less dense, it can go up. That's why the hot air balloon operates in the morning or afternoon. At these times, the surrounding air is quite hot. OK. How to increase the efficiency of hot air balloons to make them lighter and easy to float?

Student₃: Material.

Student₄: Its weight should be small.

Ali: OK. Normally, the carrier (the basket) that is used to contain riders should be bigger in terms of its size. Then, we must use bigger balloons, the bigger size of balloons. So, it has a bigger what? A bigger buoyant force, right? Thus, it can be filled with more hot air. OK.

[Code: AL-VOR-July 22-23]

Ali told students that the hot air balloon must have a weight lesser than the buoyant force to allow it to float in the air. The balloon example applies Idea C regarding flotation where the weight of an object must be smaller than the buoyant force. Ali added his explanations by saying that that hot air balloons should use a greater size of the balloon to allow it to experience a greater buoyant force.

Teaching episode 6: Idea A. In the same lesson, Ali taught students the application of Idea A, a hydrometer (Objective 2). He used the questioning during whole class discussion activity. Representations used were VS, WS, P, and RLS. Figure 42 shows the application of Idea A, a hydrometer. Ali used it as the slide of his teaching.

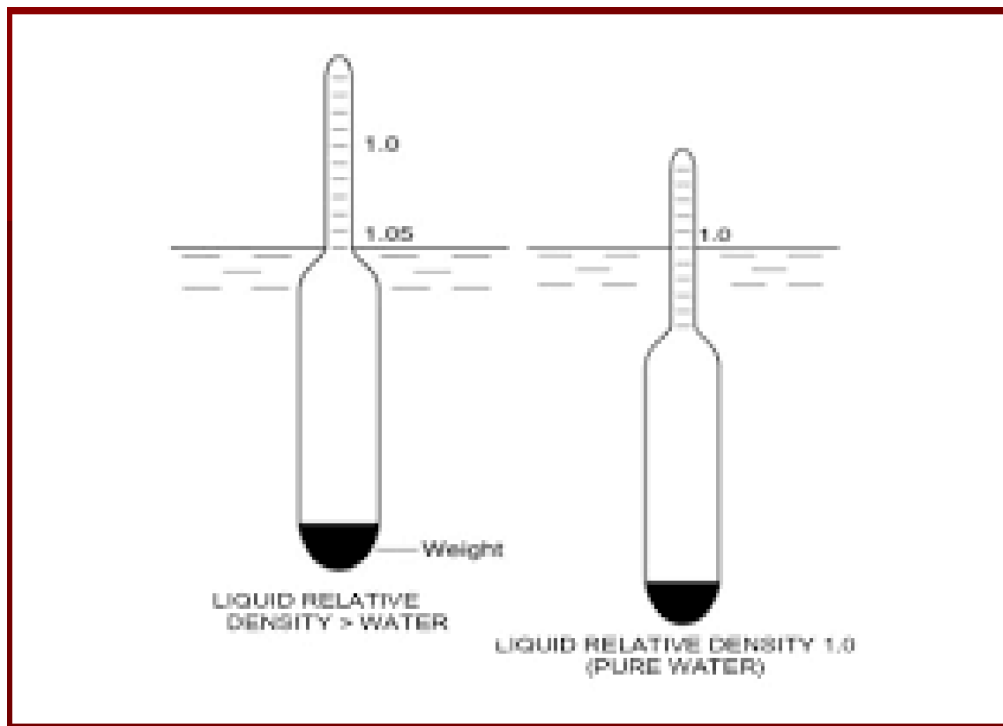


Figure 42. The application of hydrometers.

Ali engaged in dialogue with students about the use of a hydrometer.

Ali: OK. How to measure the density of a liquid? What type of instrument will we use?

Student₁: Barometer.

Ali: A barometer is to measure pressure.

Student₂: Hydrometer.

Ali: Yes, that's it. Hydrometer. A hydrometer is related to Archimedes' principle. We place a hydrometer vertically, so it does not topple. If the density of a liquid is high, will the hydrometer float higher or deeper? What happens to the hydrometer then?

Student₃: Goes higher.

Ali: It goes higher, right? If I compare, you can see the difference of the level of the hydrometer (Figure 42). One liquid is less dense, and the other is denser. If the density of the liquid is high, then the buoyant force becomes greater. The weight of the hydrometer is the same, but the liquids are different in densities. The higher the density of a liquid, the more the hydrometer floats.

[Code: AL-VOR-July 22-26]

The hydrometer is used to determine the density of a liquid. Ali told students that the hydrometer shown in Figure 42 could float better if the density of

a liquid is high. The same hydrometer will sink more if it is placed in a less dense liquid.

In the same lesson (lesson one), Ali taught students Idea A regarding the weight of liquid displaced and the buoyant force. He used the notes that he made himself and distributed the notes to students. The notes were mostly fill-in-the-blank notes where students put their answers on the notes. Ali used the questioning during whole class discussion activity for teaching using the notes. He guided students to fill in the blanks in those notes.

Figure 43 shows the notes on Idea A.

3.5 ARCHIMEDES'S PRINCIPLE

Definition	Archimedes' Principle: When an object is _____ or _____ immersed in a fluid, the upthrust or _____ on it is equal to the _____ of fluid displaced.
------------	--

Figure 43. Written notes on Idea A.

Ali engaged in conversation with students about the notes in Figure 43.

Ali: The definition of Archimedes' principle. When an object is?

Student₁: *Partially* or *fully*.

Ali: Yes it is. *Partially* or *fully* immersed in a liquid, the upthrust or ...?

Student₁: *Buoyant force*.

Ali: Yes it is. *The buoyant force* on it is equal to the *weight* of fluid displaced. We can use upward force, buoyant force, or upthrust force.

(*Italic words* are answers for the blank space).

The note in Figure 43 was the written representation while the dialogue was the verbal representation. Ali taught students Idea A of Archimedes' principle using written notes. He asked students to give ideas on the blank space of the notes. However, Ali provided the answer on the *weight* of the fluid displaced, the end of the sentence (*italic words* are the answer).

Teaching episode 7: Idea B. In the same lesson, Ali taught students Idea B regarding the loss of weight. It was his first effort to teach students Idea B. He did not teach Idea B in the previous episodes. He continued using the notes given to students. The activity of questioning during whole class discussion was used. Ali used the representations of VS, WS, F, RLS, and P.

Figure 44 shows the notes about Idea B.

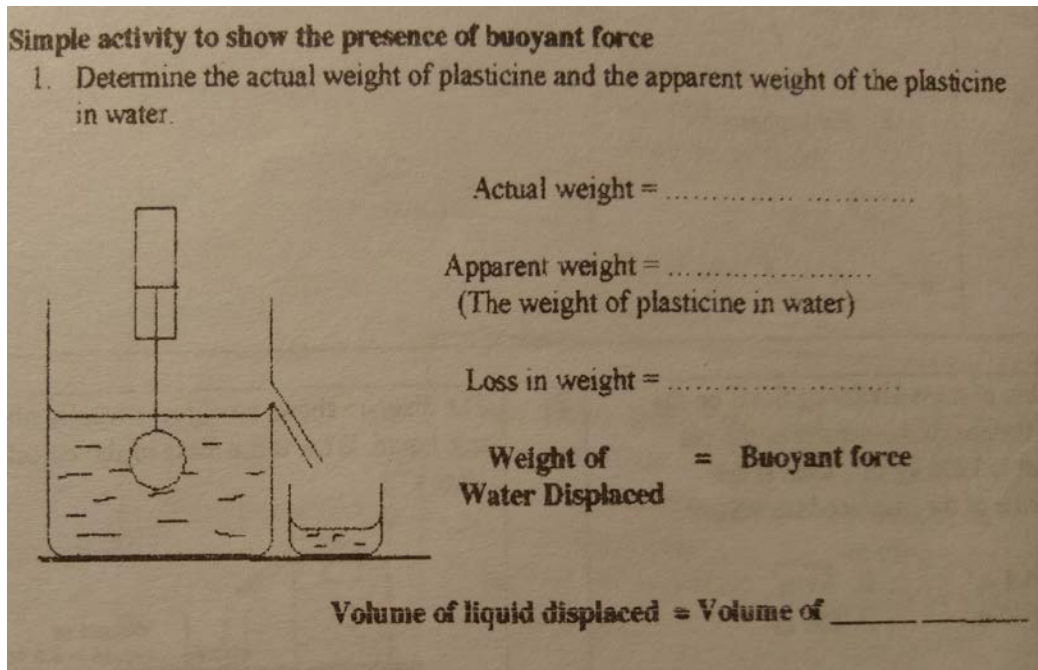


Figure 44. The weight loss of an object.

Ali used the questioning during whole class discussion activity for teaching Idea B using Figure 44.

Ali: OK. A simple activity to show the presence of buoyant force. Determine the actual weight of plasticine and the apparent weight of the plasticine in water. No values are given, right? You just put unknown. The symbol of weight is W , right? Put the symbol of W_1 for the actual weight. Then, the apparent weight. What is it? The weight of plasticine in water. Put it as W_2 . If you compare W_1 and W_2 , which one is bigger?

Student₁: W_1 .

Ali: Why W_1 ?

Student₁: Buoyant force.

Ali: Yes, because when the plasticine in water, there is another force acting on the object which is the buoyant force. So, the loss of weight is W_1 minus W_2 . If you place the plasticine inside the beaker or the Eureka tin, the water flows out. So, the weight of water displaced is equal to the buoyant force. Then, the volume of liquid displaced is equal to the volume of what?

Student₂: The object.

Ali: Yes, that's it. The object or the plasticine.

[Code: AL-VOR-July 22-29]

Ali taught students Idea B regarding the loss of weight using the diagram in Figure 44. The diagram shows plasticine immersed into the water. Ali asked students to put symbols of the actual weight as W_1 while the apparent weight or the weight of the plasticine in the water as W_2 . Ali asked students which one is bigger, W_1 or W_2 . A student said that W_1 is bigger than W_2 due to the buoyant force. The loss of weight was calculated by deducting W_1 by W_2 . Ali asked students about the volume of liquid displaced, and a student responded by saying that it is equal to the volume of an object or the plasticine.

Teaching episode 8: Idea C. In the same lesson, Ali taught students Idea C regarding flotation. He continued using the notes. The lecture activity was used. He adopted the representations of VS, WS, P, F, and RLS. Figure 45 shows the diagram of a floating object.

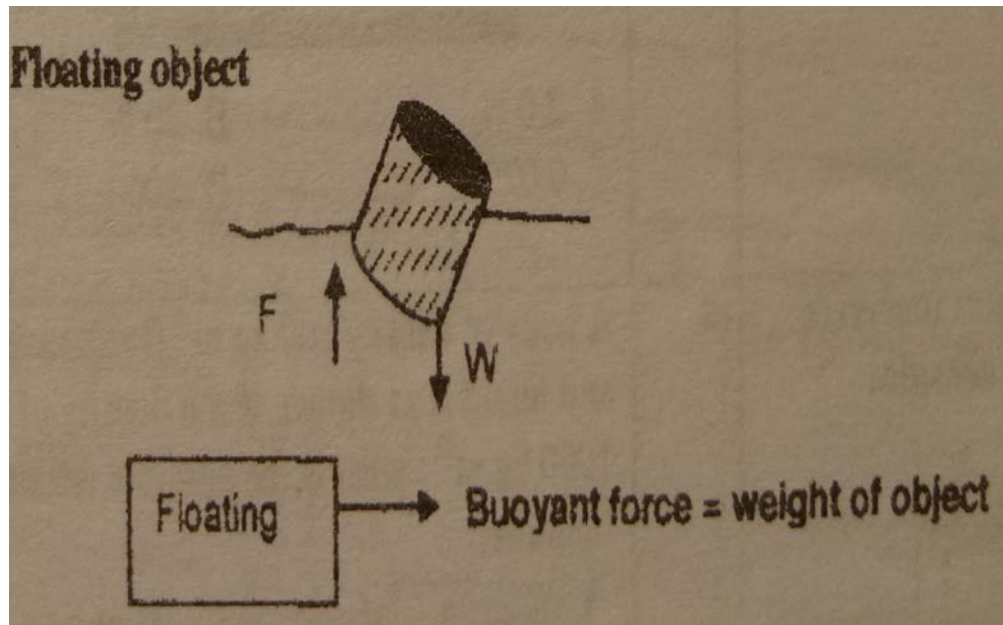


Figure 45. A floating object.

Ali gave a brief lecture about flotation.

OK. Next, a floating object. Two forces act on the object, F_B (buoyant force) and W (the weight of the object). The buoyant force is equal to the weight of the object or $F_B = mg = \rho Vg$. Please memorize this formula. It is crucial. You need to know how to use this formula.

[Code: AL-VOR-July 22-35]

Ali wanted students to understand how to use the formula of $F_B = mg = \rho Vg$ for the flotation case. For a floating object, its weight is equal to the buoyant force.

Teaching episode 9: Idea A. In the same lesson, Ali taught students Idea A. He gave students an example of a quantitative question involving those two ideas. He used the questioning during whole class discussion activity.

Representations used were VS, WS, RLS, and F. Figure 46 shows the quantitative question.

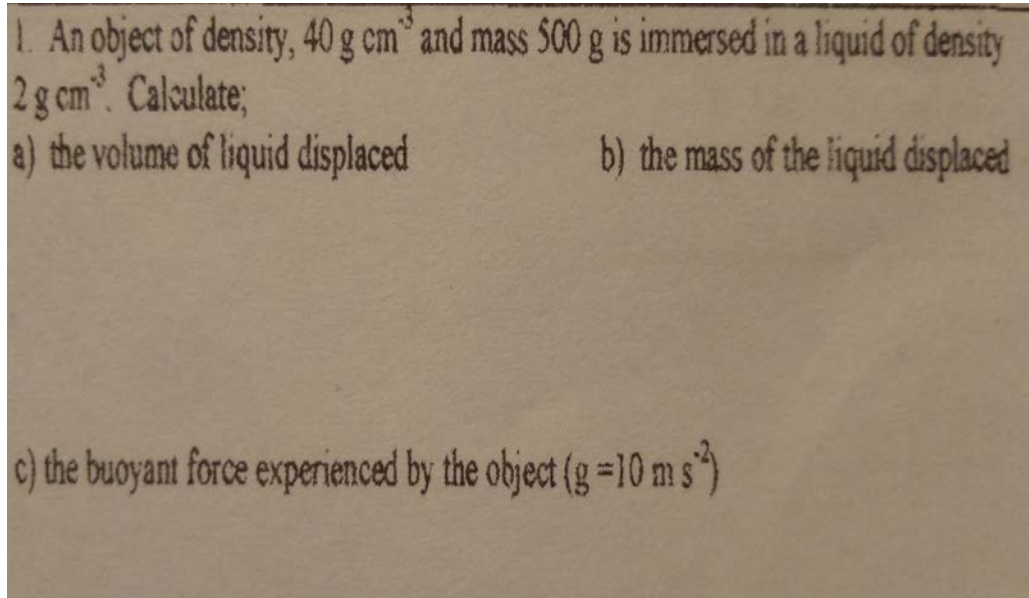


Figure 46. A quantitative question on Idea A.

Ali engaged in dialogue with students regarding the question in Figure 46.

Ali: OK. Let's try this question. The volume of liquid displaced is equal to the volume of the object. You must find the object's volume. The value of the density of the object is 40 g cm^{-3} . Then, what formula must we use?

Student₁: $F_B = pVg$.

Ali: $F = pVg$? Carefully notice the information given.

Student₂: The density of the object is given, right?

Ali: Yes, it is.

Student₃: Then we need to find the mass, right?

Ali: The volume of the liquid. The volume of the liquid is equal to the volume of the object, right?

Student₄: Is the volume of the liquid equal to the volume of the object?

Ali: If we put a tin into water, some water flows out, right? So, the volume of liquid displaced is equal to the volume of the object, right?

Student₄: Oh. Yes. Oh my God!

Ali: Then, the volume of the object, right? Why so complicated?

Student₄: Haaa!

Ali: So, what formula must you use? $\rho = m/V$, right? Because the volume of liquid displaced is equal to the volume of the object, right? The density, ρ , is given and mass, m , is given too. You can find the volume, V , using the formula of density, $\rho = m/V$.

Student₅: 12.5 cm^3 .

Ali: Yes, that's right.

[Code: AL-VOR-July 22-31]

The dialogue indicates the central role of the volume of an object in Idea A regarding the weight of liquid displaced. Using the formula of $F_B = \rho Vg$, V is the volume of liquid displaced. Since the object in the question is an immersing object, its volume is equal to the volume of liquid displaced. The object's density is given as 40 g cm^{-3} , and its mass is 500 g. Students can find the volume of the

object using the formula of density, $p = m/V$, where p is the density of the object, m is the mass, and V is the volume. The volume of the object now is equal to the volume of liquid displaced because it is an immersing object. In the dialogue, Ali already suggested to students the idea that volume of the liquid displaced is equal to the volume of the object. Students, however, were not familiar with the critical point. A student asked him, “Is the volume of the liquid equal to the volume of the object?” Ali repeated the central point stated, and students started to realize what it meant. Students got the value of the volume of liquid displaced as 12.5 cm^3 .

For question 1(b), students just needed to apply the formula of density, $p = m/V$. Since the volume of liquid displaced is known from question 1(a) as 12.5 cm^3 , and the density of the liquid is given in the question, 2 g cm^{-3} , students got the value of 25 g. The dialogue is here:

Ali: OK. Question 1(b). Mass of the liquid displaced. Find the mass of the liquid displaced.

Student₁: 25.

Ali: 25? OK. Just now, the volume of the liquid displaced is 12.5 cm^3 , right? The density of the liquid is given by 2 g cm^{-3} . So, 25, what is the unit?

Student₁: Gram.

Ali: Gram, g. OK.

Ali asked students to solve question 1(c) at home as homework. To solve the question, students needed to apply Idea A, $F_B = pVg$. The

value of ρ is 2 g cm^{-3} (given by the question), V is 12.5 cm^3 (the answer from question 1(a)), and g is 10 m s^{-2} . Thus, students can get the magnitude of the buoyant force. Students should be able to convert the unit of density, g cm^{-3} to kg m^{-3} , and the unit of volume, cm^3 to m^3 .

Ali ended the first lesson in this episode.

Teaching episode 10: Idea C. In the second lesson, Ali used written questions obtained from a commercial book that he purchased. He photocopied several qualitative questions on Archimedes' principle and distributed those questions to students. Those questions mimicked the national exam questions. The activity of teaching is questioning during whole class discussion. He used VS, WS, and RLS representations for the first question he discussed with his students. G, T, F, M, and P representations were not evident.

Ali was captured saying this to students:

Try to do the question by yourself before you discuss with your friends. You may not totally understand Archimedes' principle if you just discuss with your peers. Please do the questions by yourself. You cannot discuss questions during examinations. If you talk in class, you take a lot of time. Please do the question by yourself.

[Code: AL-VOR-July 23-3 & AL-VOR-July 23-4]

Ali reminded students to solve those questions given to them by themselves and not discuss them with their friends. He said that students could not discuss during examinations. Hence, they must be able to do the question by themselves.

Ali started the discussion with the first question regarding Idea C on flotation. The question was about the application of hot air balloons (Objective 2 and 3). Figure 47 shows the question. He gave students around 3 minutes to answer the question.

Jadual 3 menunjukkan empat belon udara panas P, Q, R dan S dengan ciri-ciri berbeza.

Table 3 shows four hot air balloons P, Q, R and S with different features.

Belon Balloon	Saiz dan isi padu Size and volume	Bilangan penunu Number of burners	Jenis fabrik Type of fabric	Suhu udara dalam belon Temperature of air inside the balloon
P	Kecil dan 800 m ³ Small and 800 m ³	1	Nilon Nylon	100 °C
Q	Besar dan 2 500 m ³ Large and 2 500 m ³	2	Nilon Nylon	120 °C
R	Besar dan 2 500 m ³ Large and 2 500 m ³	1	Kanvas Canvas	60 °C
S	Kecil dan 800 m ³ Small and 800 m ³	2	Kanvas Canvas	70 °C

Jadual 3 / Table 3

Anda dikehendaki menyiasat belon udara panas yang boleh membawa tiga atau empat orang penumpang ke altitud tinggi dalam masa yang singkat. / You are required to investigate the hot air balloon which is able to carry three or four people to a higher altitude in a shorter time.

Tentukan belon yang paling sesuai dan beri sebab bagi jawapan anda.

Determine the most suitable balloon and justify your choice.

Figure 47. The question on the application of hot air balloons.

[Code: AL-DOCM-July 23-1]

Ali used the questioning during whole class discussion activity for teaching the question on hot air balloons that apply Idea C regarding flotation.

Ali: Yesterday, we learned about hot air balloons (Episode 5). For its characteristics, just choose from the choices given. For the size and volume of a hot air balloon, which one we want to choose?

Student₁: Bigger size.

Ali: So, we choose the large size and 2500 m³. A bigger size or more volume. What is the reason?

Student₂: Can attract more air particles.

Ali: No.

Student₃: Carry more people.

Ali: Carry more people? Yesterday, I explained how to increase the efficiency of a hot air balloon. I mentioned a bucket. The answer is, it can displace more hot air or store more hot air. If it can store more hot air, then what?

Student₄: There is a higher buoyant force.

Ali: Yes, that's right. A higher buoyant force.

[Code: AL-VOR-July 23-7]

Ali suggested an answer to the question of why a hot air balloon should have a bigger size and volume. He told students that it allows the balloon to displace more hot air. A student suggested that the displacement of more hot air could produce a greater buoyant force. Ali agreed with the student's idea.

Ali continued the dialogue about the point on the number of burners, type of fabric, and the temperature of the air inside the balloon.

Ali: Next. The number of burners.

Student₁: More.

Ali: Higher numbers or two. Why?

Student₁: To produce heat air quickly.

Ali: Yes, that's right, or heat air faster. OK. Next. Type of fabric.

Student₂: Nylon.

Ali: Yes, that's right. Nylon. Why?

Student₁: Lighter.

Ali: Yes, it is. Lighter.

Student₂: What about that it can withstand more heat?

Ali: It can also do that. What about the temperature inside the balloon?

Student₃: Higher temperature.

Ali: Higher temperature or 120⁰C. Why?

Student₃: The density of the air inside the balloon is less dense.

Ali: Yes it is. Hot air is less dense, or hot air has a lower density than the cold air. Or the hot air is lighter. Finally, choose the best balloon. What is your answer?

Student₄: Balloon Q.

Ali: Yes, that's right. Balloon Q.

[Code: AL-VOR-July 23-7]

Ali taught students Idea C regarding flotation using the question on hot air balloons. The qualitative question asked students to choose the best balloon that could bring three or four people to a higher position in a shorter period. A hot air balloon must have a weight that is less than the buoyant force. The buoyant force magnitude must be large enough to lift the balloon into the air. For this purpose, the volume and size of the balloon must be big. There should be more burners because a greater number of burners can quickly heat the air. The fabric used should be lighter, like nylon, to allow a lower density of a balloon. The temperature inside the balloon must be higher because hotter air is less dense than colder air. Therefore, students chose the balloon Q because it fulfilled all the necessary requirements for having the best design of a hot air balloon.

Teaching episode 11: Idea D. In the same lesson, Ali taught students Idea D regarding immersion. He used a written question about the application of Idea D, submarines (Objective 2 and Objective 3). The activity of questioning during whole class discussion was used. Ali used VS, WS, and RLS representations. He asked students to solve the question individually. He then discussed the answers to the question with students.

Figure 48 shows the question regarding submarines.

Anda diminta menyiasat ciri-ciri bagi empat kapal selam dalam Jadual 4.

You are required to investigate the characteristics of four submarines shown in Table 4.

Kapal selam <i>Submarine</i>	Isi padu tangki ballast <i>Volume of ballast tank</i>	Bilangan tangki udara <i>Number of air tank</i>	Tekanan maksimum yang boleh ditahan <i>Maximum pressure to be tolerated</i>	Bentuk kapal selam <i>Shape of submarine</i>
P	3 000 ℓ	15	4.5 atm	Segi empat <i>Rectangular</i>
Q	2 500 ℓ	30	6.0 atm	Larus <i>Streamline</i>
R	350 ℓ	3	6.1 atm	Larus <i>Streamline</i>
S	400 ℓ	1	2.0 atm	Pentagon <i>Pentagon</i>

Jadual 4 / *Table 4*

Terangkan kesesuaian setiap ciri kapal selam dan tentukan kapal selam yang boleh bergerak laju, berada lebih lama di dalam air laut yang lebih dalam dan boleh membawa lebih banyak anak kapal. Beri sebab bagi pilihan anda. / *Explain the suitability of each characteristic of the submarines and determine the submarine which can travel faster, stay longer in deeper sea water and able to carry more crews. Give reasons for your choice.*

Figure 48. The question about submarines, the application of Idea D.

[Code: AL-DOCM-July 23-2]

Ali gave students around 3 minutes to answer the question. When students had completed answering the question, Ali discussed the question with the whole class.

Ali: Look at the question (Figure 48). Which submarine do you think can travel faster and stay longer in deeper seawater and which will be able to carry more crews?

Student₁: Submarine Q.

Ali: OK. Please state characteristics and reasons.

Student₂: Teacher, what is the function of an air tank?

Ali: Oxygen tanks. They are used for the purpose of breathing when a submarine is going deeper into the sea like when a diver brings along an oxygen tank when diving into a deep sea.

Student₂: Oooo.

Ali: The use of air tanks is to store oxygen. Why do we need a higher or lower number of air tanks? Please think about it.

(Students were trying to answer the question in written forms on the question given)

Ali: OK. Let's discuss the question now. Look at the question. We want to choose a submarine that can travel faster, stay longer in deeper seawater, and carry more crews. Look at the volume of ballast tanks. Which one is right?

Student₃: Q.

Ali: OK. Please state “bigger volume” or “more volume” of ballast tanks, 2500 liters. Try to imagine. You drink a bottle of 1.5 liters of water. Now, the volume is 2500 liters. Why do we need to have a bigger volume of ballast tank?

Student₄: It can go deeper or sink deeper.

Ali: It can displace or store more water and can increase the buoyant force, and then it can easily sink deeper.

Student₃: What if I say the submarine can become denser?

Ali: Yes. It can do that, too. If it pumps in more water, then the submarine can be denser. Next. The number of air tanks.

Student₄: More.

Ali: More – actually, many (30 tanks), because many tanks could supply sufficient oxygen for the crews. Next. What about the maximum pressure to be tolerated?

Student₅: Higher pressure.

Ali: Why?

Student₅: To withstand the high pressure.

Ali: Yes, that’s right. Next. What about the shape of a submarine?

Student₆: Streamlined.

Ali: Why?

Student₆: To travel faster.

Ali: It can decrease water resistance. You cannot say, “it travels faster” because those words are already used in the question.

Student₇: It can increase its speed.

Ali: Yes, it can. It will increase the speed of the submarine. Which submarine is the best?

Student₈: Submarine Q.

Ali: Yes, it is.

[Code: AL-VOR-July 23-10 & AL-VOR-July 23-11]

Ali guided students to discover the answer to the question about submarines that applies Idea D regarding immersion. The element of the volume of the ballast tank was the critical point of Idea D. A student suggested that a large volume of ballast tanks allows a submarine to sink deeper. The submarine becomes denser when more water is filled into the ballast tank. Ali added that with the big volume of ballast tanks, the submarine could store more water.

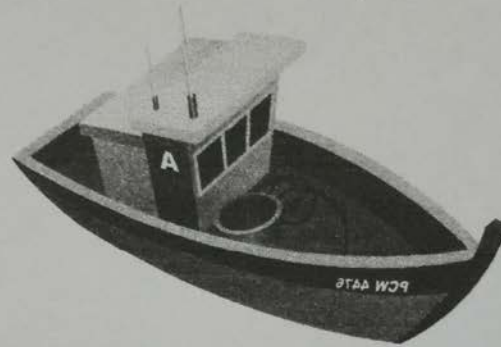
The question also asked students to apply the idea of pressure in liquids (the maximum pressure exerted on the submarine) and Bernoulli’s principle (the shape of the submarine). At this time, Ali had taught the pressure in liquids at the beginning of the unit of Force and Pressure. He, however, had not taught Bernoulli’s principle yet.

Ali also reminded students not to repeat the same words used in the question like “travel faster.” He wanted students to rephrase their answers because

students are not allowed to use the exact words used in a question when answering the question.

Teaching episode 12: Idea C. In the same lesson (lesson two), Ali taught students Idea C regarding flotation. He used the question on the application of Idea C, boats (Objective 2 and 3). Ali continued to use the questioning during whole class discussion activity. He employed VS, WS, P, and RLS representations. Figure 49 shows the question about a boat.

Anda dikehendaki memberi beberapa cadangan tentang bagaimana mereka bentuk bot dalam Rajah 5 untuk menambah daya keapungan dan lebih selamat. Terangkan cadangan anda berdasarkan aspek-aspek berikut:
You are required to give some suggestions on how to design the boat in Diagram 5 as to increase the floating force and safer. Explain the suggestions based on the following aspects:



Rajah 5 / Diagram 5

- i. Bahan yang digunakan / *Material used*
- ii. Bentuk bot / *Shape of boat*
- iii. Ketumpatan bot / *Density of boat*
- iv. Komponen tambahan / *Additional components*
- v. Ciri keselamatan / *Safety feature*

Figure 49. The question about a boat.

[Code: AL-DOCM-July 23-3]

Ali first asked students to try to answer the question individually. He gave students around 3 minutes to respond to the question. He then discussed the question in Figure 49 with the whole class.

Ali: OK. Look at the question (Figure 49). Material used.

Student₁: Strong material.

Ali: That is acceptable. However, you must ensure that it will not break easily. We can also use light materials. Next: the shape of the boat.

Student₂: Streamlined shape.

Ali: Yes, that's right. A streamlined shape is to reduce what?

Student₃: Water resistance.

Ali: Water resistance or water friction. A boat usually has a streamlined shape. Then, what about the density of the boat?

Student₄: Low.

Ali: Low density. What is the reason?

Student₅: For a higher buoyant force.

Ali: Yes, that's right. Light density or higher buoyant force. Then, additional components.

Student₆: Radar.

Ali: Good. Radar. Or GPS. What is the reason?

Student₆: The boat can be detected easily.

Ali: OK. The boat can be detected during the night. OK. Next.

Safety feature.

Student₇: Life jackets.

Ali: Yes, indeed. Life jackets.

Student₈: Buoys.

Ali: Right. Buoys. What is the reason?

Student₇: To save crews.

Ali: In what ways can it save them? It can ensure crews can float or prevent them from drowning when something bad happens to the boat.

Ali discussed with students the application of Idea C (flotation) which is a boat. A student suggested that a boat's body should be strong, and Ali added that it also should also be designed using light materials. Then, the shape of the boat should be a streamlined structure to reduce water resistance. This is the application of Bernoulli's principle that Ali had not taught yet. Regarding the density of the boat, a student suggested a low density because it can allow the boat to experience a greater magnitude of buoyant force. Meanwhile, the boat may use extra tools like radar, as suggested by a student. Ali added that a GPS could also be used to detect the location of the boat, especially at night. Finally, Ali discussed safety features with students. A student suggested the use of life jackets. She said that they would save crews. Ali refined the student's idea by

saying that life jackets or buoys can allow crews to float when they face an unexpected circumstance that force them to swim.

After that, Ali taught students about Bernoulli's principle. He mostly lectured and used the questioning during whole class discussion activity. The principle of Bernoulli was important because Ali had not taught that topic yet. He used this episode to teach students the principle because some questions he used like boats and submarines apply the Bernoulli's principle in terms of a streamlined shape. He used notes given to students as he did when teaching the Archimedes' principle. Ali ended the second lesson of Archimedes' principle in this episode.

Teaching episode 13: Idea A and closure. In this third lesson, Ali initially taught students Bernoulli's principle. He continued teaching the principle of Bernoulli from the previous lesson and episode (episode 12). Ali mentioned to students that:

Bernoulli's principle is much easier than two previous principles – Archimedes' and Pascal's principle.

[Code: AL-VOR-July 29-15]

Ali then taught students the application of Idea A regarding the weight of liquid displaced, specifically the Plimsoll symbols used by ships. He used the lecture activity and used representations of VS and RLS. No P, M, WS, F, G, and T representations were used.

Ali gave a brief lecture about Plimsoll lines.

If you see a ship, there is something on the bottom part of it. We call those Plimsoll lines. You will see some symbols like Tropical Salt Water, Salt Water in Summer, Salt Water in Winter, etc. They are different lines. Plimsoll lines are an indicator for a ship to know how much weight could be put on a ship. If it has more loads at a lower density of water, the ship will sink. The lines serve as indicators.

[Code: AL-VOR-July 29-19]

Ali explained that Plimsoll lines on a ship act as indicators for crews to know the suitable amount of loads that can be brought. When the ship travels across different oceans, each has different densities. It will sink when it has many loads while traveling on a sea that has a lower density. The Plimsoll lines used by ships apply Idea A regarding the weight of liquid displaced. The greater value of the density of a particular sea can allow a ship to float better. However, crews must be aware that each sea has different densities. Hence, the ability to float varies depending on the density of a specific sea.

Ali completed teaching Archimedes' principle with this episode.

Main characteristics of Ali's teaching activities. Based on the whole teaching episodes, Ali utilized two teaching activities: (1) lectures and (2) questioning. Other activities like demonstrations, lab work, small group discussion, and building physical models were not evident.

Lectures. Ali conducted this activity to explicate concepts, formulae, and applications of Archimedes' principle mostly in modest manners. First, he shortly lectured on Idea A, which was about the weight of liquid displaced in episode 1. Then, in episode 3, he lectured about Idea C, which was about flotation, and provided a detailed lecture that explained that the weight of an object is equal to the buoyant force exerted on the object. He used the application of ships that applied Idea C when explaining the flotation case. Later, in episode 8, Ali shortly lectured on Idea C and explained the formula of flotation, $F = mg$. Finally, in episode 13, he briefly lectured about Plimsoll lines that apply Idea A. Overall, the lecturing activity was all teacher-centered because the teacher directly explained the concepts, formulae, and applications of Archimedes' principle to students.

Questioning. Ali adopted this activity to:

- (1) Check students' understanding of his lectures or explanations. He asked students a question about Idea A from a slide that he used (episode 1) but students responded that they did not understand his lectures or explanations. He further explained the ideas and applications and rechecked students' understanding by asking more questions about the ideas and applications. Students then seemed to understand the ideas and their applications. The same techniques were applied in episodes 2 (Idea A), 3 (Ideas C and A) 4 (Ideas C and D), 5 (Idea C), 6 (Idea A).
- (2) Discuss written notes. Using the handouts given to students, in episode 6, Ali used questioning activities to discuss written questions in the handouts

given to students. He asked students questions based on the handouts' questions and students responded to the questions verbally, and Ali gave feedbacks to students' responses. They then wrote their answers on the worksheets. The same techniques were used in episodes 7, 8, and 9.

- (3) Discuss questions that mimicked the national exam questions. In episode 10, Ali used questioning activities to discuss with students the questions that followed the national exam format. He asked questions to students based on the questions given and asked them to relate their answers with the previous lesson's learning. Students responded to Ali's questions and he confirmed his students' answers as being either right or wrong. He also suggested some answers when the students missed important points in their answers or had no ideas, and asked students not to repeat words that were used in a question to follow the national exam requirements. This questioning technique was also applied in episodes 11 and 12.

Overall, the questioning activities were mainly teacher-centered because Ali primarily led the dialogue with students using the notes and written questions that followed the national exam requirements. He usually initiated the dialogues with questions (Initiation), and then students gave responses to his questions (Response). He then verified students' response, usually by telling them either they were right or wrong. He also suggested some answers when students found it difficult to give complete answers (Feedback). This technique of questioning was

of the IRF type (Initiation-Response-Feedback) – more teacher-centered than student-centered.

Main characteristics of Ali’s translation of representations in selected episodes. Selecting episodes and the way of presenting the sequences of representations for Aishah were done in the same ways as was done for Aminah and Aishah. The selected episodes for Ali were episodes 2, 6, 9, and 13.

In episode 2, the sequence of translation was $WS_{a1} \rightarrow RLS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1}$. This translation means:

Ali used a slide to teach students Idea A and he connected the slides with a real-life situation of a floating apple in water and seawater ($WS_{a1} \rightarrow RLS_{a1}$). He engaged in dialogue with students about the real-life situation through question-and-answer activities ($VS_{a1} \rightarrow VS_{s1}$). Hence, the translation was $WS_{a1} \rightarrow RLS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1}$.

Ali used WS, RLS, and VS in this episode. He did not use other modes, G, T, P, F, and M.

In episode 6, Ali used the sequence of translation of $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{b1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow WS_{s1}$. This translation is read as:

Ali used a slide that showed a picture of a hydrometer, which is a real-life situation illustrating Idea A, and gave written explanations of the use of the hydrometer ($RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1}$). He then discussed the hydrometer with students through questioning

activities ($VS_{a1} \rightarrow VS_{s1}$). After that, he used a note to teach students about Idea A (WS_{b1}). He discussed with students the notes given and asked students to write their answers on the note ($VS_{a2} \rightarrow VS_{s2} \rightarrow WS_{s1}$). Thus, the translation was $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{b1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow WS_{s1}$.

In this episode, Ali used the modes of RLS, P, WS, and VS. He did not use G, T, M, and F.

In episode 9, Ali translated the modes of representations as $RLS_{a1} \rightarrow WS_{a1} \rightarrow F_{a1} \rightarrow VS_{a1} \rightarrow VS_{s2} \rightarrow W_{s1}$. It means that:

Ali used a written question to teach students about a real-life situation of an immersed object in a liquid, and students needed to use the formula of $F = Vpg$ to solve the quantitative question ($RLS_{a1} \rightarrow WS_{a1} \rightarrow F_{a1}$). He then discussed the question with students using questioning activities and finally asked them to write down their solutions into the notes given to them ($VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{s1}$). Hence, the full translation becomes $RLS_{a1} \rightarrow WS_{a1} \rightarrow F_{a1} \rightarrow VS_{a1} \rightarrow VS_{s2} \rightarrow WS_{s1}$.

Ali used the modes of RLS, WS, F, and VS in this episode. Other modes, G, T, M, and P were not evident.

In episode 13, the sequence of translation was $RLS_{a1} \rightarrow VS_{a1}$. This translation means that Ali shortly explained Idea A, specifically, the real-life situation of Plimsoll lines on a ship $RLS_{a1} \rightarrow VS_{a1}$. This translation was the

shortest among all of the selected episodes. He did not use G, T, M, WS, F, and P modes and just used RLS and VS.

Overall, Ali used the modes of representations of RLS, VS, WS, F, P, and F in those selected episodes about Idea A and its associated ideas. The use of modes of G, T, and M were not evident. Ali mainly used VS, WS, P to teach students about Idea A and its related ideas through questioning activities via dialogues using written materials given to students. He emphasized RLS and F representations where these two modes were mainly translated into VS, WS, and P.

Amplifiers and filters. This section explains Ali's amplifiers and filters of teaching that included instructional goals, reasons for adopting particular teaching activities, and contextual and/or personal factors that shaped his instruction.

Contextual amplifiers. There were two types of contextual amplifiers: (1) national contextual amplifiers and (2) school contextual amplifiers. The first national contextual amplifier was the obligation to finish teaching the national syllabus. Finishing the syllabus was imperative because every student would be evaluated on each physics topic covered in the national curriculum when taking the national examination. Hence, completing the syllabus was a must for Ali.

The second national contextual amplifier was Ali's efforts to implement recommendations of the national curriculum on instructional objectives. He said that:

Learning goals were based on learning objectives set by the national curriculum of physics. I follow the learning objectives stated in the national curriculum. Those objectives are the guide of my teaching. I tried to achieve the objectives stated in the national curriculum.

[Code: AL-PREIN-June 24-25, AL-PREIN-June 24-26, AL-PREIN-June 24-27, AL-POSTIN1-Aug 23-6, & AL-POSTIN1-Aug 23-7]

The third national contextual amplifier was the national recommendation regarding teaching activities for teaching Archimedes' principle. The national curriculum recommends that teachers use inquiry-based learning, specifically lab work, discussions, and models. Ali intended to use all of those, especially the lab work activities. However, he did not adopt the lab work activity in his teaching. He instead used questioning during whole class discussion and lecture activities.

The fourth amplifier was both a national and school contextual amplifier, which was the goal of preparing students for the national exam and school exams. School exams followed the national exam format. He mentioned that:

Types of questions given to students use the format of the national exam. It is to make students familiar with the techniques to answer the national exam questions.

[Code: AL-POSTIN1-Aug 23-42]

Another type of amplifier was school contextual amplifier. One school contextual amplifier was Ali's school status. He said that:

My school is a school with a high academic reputation. Students entering this school are excellent students. They have high expectations for academic achievement compared to students in other schools. I usually give my students high-level questions that are open-ended.

[Code: AL-PREIN-June 24-36, AL-PREIN-June 24-37, AL-PREIN-June 24-38, & AL-PREIN-June 24-39]

Contextual filters. The first contextual filter found was class size. It was a school filter. Ali mentioned that:

It was hard to control students' hands-on activities when a class has a lot of students. I should monitor their work because they tend to play with laboratory equipment. It was difficult for me to control them all in the lab. A lab assistant was supposed to be in the lab.

[Code: AL-POSTIN2-Aug 26-51 & AL-POSTIN2-Aug 26-52]

The second contextual filter was time constraints. It also was a school filter. As a teacher, he did not just teach but also needed to do other tasks besides teaching like handling his school's programs. Ali felt that those extra tasks limited his time for preparing instruction well. This issue involved the time constraint for planning instruction, which left him unable to conduct experiments even though

the national curriculum specifically recommends it. The issue was teachers' workloads. Ali said about this challenge:

Each teacher is involved with extra programs that are not directly related to teaching and learning. If these additional duties often burden teachers, they affect teachers' ability to teach. Teachers' availability in the classrooms would be less or teaching cannot be done optimally. When those extra responsibilities occur, teachers' time for preparing instruction becomes limited.

[Code: AL-PREIN-June 24-60]

Ali described more about the problem of time constraints:

I actually wanted to adopt a laboratory work activity for teaching Archimedes' principle. I can use Eureka cans and other apparatuses. However, due to time constraints, I cannot use the activity. Instead, I used lectures and tried my best to explain the principle in detail.

[Code: AL-POSTIN2-Aug 26-37 & AL-POSTIN2-Aug 26-

38]

The problem with time constraints had changed Ali's intention to use the lab work activity for teaching Archimedes' principle. He ended up with using the lecture activity, including pictures and verbal representations for explaining to students the ideas of Archimedes' principle. For instance, in teaching episode 3, he

lectured students on Idea C regarding flotation and used a slide showing a floating ship.

Personal amplifiers. Ali indicated that he wanted students to be able to apply physics knowledge to their real lives. He mentioned that physics is a subject that has a close connection with students' lives. By linking physics with their world, they can understand those applications using physics knowledge they learned at their school. Ali stated that:

My goal of teaching physics is to make students be able to relate their real lives with science. We know that science is wide, and physics is one of the branches of science. Physics is close to students' surrounding phenomena. Thus, students need to know why a particular phenomenon can occur. The unit of Force and Pressure (containing Archimedes' principle) is also closely connected to students' real world. By learning this unit, students can strengthen their understandings of physical phenomena around them.

[Code: AL-PREIN-June 24-1, AL-PREIN-June 24-2, AL-PREIN-June 24-3, AL-POSTIN1-Aug 23-2, & AL-POSTIN1-Aug 23-3]

When teaching Archimedes' Principle, Ali taught students applications of the principle. He taught about ships in episode 3, submarines in episode 4, hot air balloons in episode 5, and boats in episode 12.

Another personal amplifier was Ali's personal knowledge about instruction and assessment. He wanted students to be able to solve questions individually instead of through discussion with other students. During teaching episode 10, he explicitly mentioned this to students:

Try to do the question by yourself before you discuss with your friends. You may not totally understand Archimedes' principle if you just discuss with your peers. Please do the questions by yourself. You cannot discuss questions during examinations. If you talk in class, you take a lot of time. Please do the question by yourself.

[Code: AL-VOR-July 23-3 & AL-VOR-July 23-4]

Ali's personal amplifier about how students should solve problems revealed that he employed the principle of individual assessment used by the national examination system. The present system of assessment is an individual-based assessment, not group based. Hence, he personalized the assessment principle in his teaching by not allowing students to discuss questions among peers. This personal amplifier was consistent with one of the contextual amplifiers regarding the national examination (see the section of contextual amplifiers).

The following paragraphs are about Ali's reasons for using particular teaching activities.

Questioning. Ali allocated a substantial amount of time using this activity when teaching Archimedes' principle, around 112 minutes out of 125 minutes. He

used this activity in all teaching episodes, except episodes 8 and 13. The exceptions of just these two episodes were the proof that he consistently used the questioning activity throughout his teaching on Archimedes' principle. In fact, he used the activity when teaching all ideas, Idea A to Idea D. He relied heavily on notes that he made himself and written questions that he obtained from the commercial book. He used those curricular materials when conducting questioning activities with students.

Ali stated several reasons for using the activity of questioning during whole class discussion. First, he wanted to know students' ideas in a particular concept and he could identify students' alternative conceptions. He said that:

My usual instructional activity is questioning. Throughout my instruction, I initially asked students questions to find out their existing knowledge about a particular concept. Then, I moved to teaching the concept followed by other questions that can strengthen students' conception.

[Code: AL-POSTIN1-Aug 23-10]

He recognized that the activity was the usual activity of his teaching. It was the reason why he consistently used the activity throughout all teaching episodes, except for episodes 8 and 13. When teaching Archimedes' principle, he always initiated dialogues with students. For instance, when teaching Idea A regarding the weight of fluid displaced, he realized that students did not understand the role of the volume of an object in determining the volume of liquid displaced. This

occurred in teaching episode 9 where a student asked him about the volume of an object and its relationship with the volume of liquid displaced. His use of the questioning activity demonstrated the potential for finding out students' current understanding of a particular idea related to Archimedes' principle. Ali could understand his students' current ideas on Archimedes' principle and help them understand it. He also found that using the questioning during whole class discussion activity could identify students' alternative conception. For instance, in teaching episode 1, Ali found that his students gave incorrect ideas about the weight of liquid displaced, Idea A. Ali corrected an idea of one of his students when she said that the weight of the water displaced is equal to the apple's weight. Ali corrected her by saying that it is equal to the buoyant force.

The second reason was to prepare students for answering exam questions. When he was teaching Idea D in episode 11, he specifically mentioned to students, during the dialogue, that they could not repeat the words that are used in a question. Ali reminded students of a technique for answering exam questions where they needed to rephrase their written answers because they are not allowed to use the exact words used in a particular exam question. All questions that were given to students imitated the national exam questions. It was consistent with one of Ali's contextual amplifiers regarding the national exam.

Lectures. Ali used this activity in teaching episodes 1, 3, 8, and 13. During those episodes, he lectured about Idea A (episode 1 and 13) and Idea C (episode 3 and 8). In total, Ali allocated 13 minutes to using the lecture activity.

Ali initially wanted to use the activity of laboratory work for teaching the Archimedes' principle. He said that:

I thought that I could use a laboratory work activity for teaching Archimedes' principle. I wanted to use Eureka tins and submerge an object into the tin. An investigation can help students see clearly the ideas of physics and strengthen their conceptions. They can conduct investigations themselves instead of me just teaching using slides. Or, I can show them a demo regarding the Archimedes' principle in front of the class.

[Code: AL-PREIN-June 24-13, AL-PREIN-June 24-58]

Ali knew that the laboratory work activity could help students learn concretely by using lab equipment such as Eureka tins in order to see the submersion of an object and the water displaced. However, he did not adopt that activity due to time constraints. This issue is explained in-depth in the section of "contextual filters."

Personal filters. One personal filter came from Ali's choice to use specific curricular materials like the written questions obtained from a commercial book. He used several questions from the book, photocopied them, and distributed them to students. Those questions directed his teaching as he continuously used the written questions in teaching episodes 10, 11, and 12. All of the questions were qualitative types and open-ended.

Chapter V: Cross-case Analysis

This chapter analyzed findings across cases according to the two research questions:

- (1) How do physics teachers teach Archimedes' principle in real classroom settings?
- (2) Why do physics teachers teach Archimedes' principle in the ways they do?

These research questions are used to organize this chapter into two parts. The first part is about the teaching practices of the teachers that consist of their subject matter knowledge (SMK) in practice and pedagogical knowledge (PK) in practice. The second part is about the reasons for their practices that were mainly about their contextual knowledge (CxK) and integration of CxK with SMK and PK.

How Do Physics Teachers Teach Archimedes' Principle in Real Classroom Settings?

The teachers' subject matter knowledge (SMK) and pedagogical knowledge (PK) in practice were primarily used to answer the first research question. SMK included the main ideas that the teachers used to teach Archimedes' principle, the order and combination of the main ideas, and the emphasis they gave to teaching the main ideas of Archimedes' principle in practice. PK included the teachers' teaching activities of lectures, lab work, questioning, and small group discussion as well as use of multiple representations

of verbal symbols, written symbols, real-life situations, pictures, formulae, and manipulatives.

Main ideas of Archimedes' principle and their organization in practice. As indicated in Chapter 4, all of the teachers taught Archimedes' principle with the same four main ideas: (1) Idea A – The weight of liquid displaced is equal to the buoyant force, (2) Idea B – The apparent loss of weight of an immersed object in a liquid is equal to the buoyant force, (3) Idea C – A floating object has a weight that is equal to or less than the buoyant force, and (4) Idea D – A submerged object has a weight that is greater than the buoyant force.

While the teachers taught the same ideas, they organized them differently. Table 7 shows the orders and combinations of the main ideas according to the various teaching episodes observed for each teacher.

Table 7

Orders and Combinations of Teaching the Main Ideas

Teaching Episodes	Cases and Ideas		
	Aminah	Aishah	Ali
1	Introduction	Introduction	Introduction
2	Idea A	Idea B	Idea A
3	Idea B	Idea A	Idea C
4	Idea A	Idea C	Ideas C and D
5	Ideas C and A	Idea D	Idea C
6	Ideas C and D	Ideas B and A	Idea A
7	Idea C	Idea C	Idea B
8	Ideas C and D	Ideas B and A	Idea C
9	Idea C	Ideas A and C	Idea A
10	Idea D	Ideas A and B	Idea C
11	Summary and closure	Idea C	Idea D
12		Ideas A and C	Idea C
13		Ideas C and D	Idea A and Closure
14		Idea C	
15		Idea A	
16		Ideas A and B, Closure	

Each teacher began with a general introduction and ended with a closing summary, but the order of ideas varied substantially. Aminah organized the ideas in the most simple and direct way using only eleven episodes. She started teaching with Idea A and taught Ideas A and B before teaching Ideas C and D. She used relatively few repetitions of the ideas (eight times) or combinations of ideas (three times). She particularly emphasized Idea C (five times), moderately emphasized Ideas A and D (three times each), and emphasized Idea B only once.

In contrast, Aishah's organization of the subject matter was much more complex. Aishah started teaching with Idea B instead of Idea A just as Aminah

did. She taught Ideas B and A before teaching Ideas C and D. She used sixteen episodes, often repeating the teaching of ideas (eighteen times) and combination of ideas (seven times). Unlike Aminah, Aishah specifically emphasized Idea A (eight times), moderately emphasized Ideas C and B (six and five times respectively), and only emphasized Idea D twice.

Ali's organization of the ideas was more like Aminah's than like Aishah's. Ali followed the same order that Aminah did where he started teaching with Idea A. Like Aminah and Aishah, he taught Ideas C and D after teaching Idea A, but he did not teach Idea B before Ideas C and D like Aminah and Aishah did. Even though he used more episodes than did Aminah, he taught the ideas mostly one at a time (eleven times) like Aminah did. He only used a pair of ideas once. Like Aminah, Ali especially emphasized Idea C. He moderately emphasized Ideas A and D (four times and twice respectively) and gave less emphasis to Idea B (once).

Within the varied orders and combinations of ideas, a few patterns were notable. Idea A was taught frequently and distributed across the episodes for all three teachers. Idea B was taught occasionally and occurred at different places. Idea C was taught often by the teachers, especially Aminah and Ali, and most often taught in the middle episodes. Idea D was not taught often and was usually combined with Idea C.

Regarding the combination of ideas, all teachers combined the teaching of the two ideas, Idea C and Idea D once or twice but at early (Ali), middle

(Aminah), or late places (Aishah) in the episodes. Other combinations were not common across the three teachers. Aminah and Aishah combined Idea A and Idea C once, while Aishah mainly combined Ideas A and B in four episodes.

Overall, the different orders, combinations, and emphases of the ideas reflected considerable differences in the teachers' subject matter knowledge (SMK) in practice. Ali's and Aminah's SMK in practice were quite similar in terms of the emphasis of teaching Ideas A, B, C, and D but their order of teaching the ideas differed considerably. As for Aishah, her SMK in practice was complex and greatly different from that of Aminah and Ali. Her organization of Ideas A to D reflected a complexity in her SMK that was not evident in the practices of the other two teachers.

Teaching activities. The teachers' teaching activities are compared in Table 8. The information in Table 8 was taken from Chapter 4, particularly from the section on main characteristics of the teachers' teaching activities.

Table 8

Main Characteristics of the Teachers' Teaching Activities

Teaching Activities	Main Characteristics		
	Aminah	Aishah	Ali
Lectures	Extensive lectures, exam preparation	Brief lectures	Modest lectures
Questioning during whole class lecture or discussion	Brief questioning, teacher-directed	Consistent questioning, IRF approaches (Initiation-Response-Feedback), teacher-directed, exam preparation	Consistent questioning, IRF approaches (Initiation-Response-Feedback), teacher-directed, exam preparation
Lab work	-	Highly structured, group work, directed students step-by-step	-
Small group discussion (lab or exam practice)	Students worked in groups, helped groups to answer questions, exam preparation	Asked groups to produce explanations of lab data, groups shared ideas, the teacher confirmed groups' answers.	-

As is evident from Table 8, the variety of teaching activities was very limited within each teacher's practices. One teacher (Aminah) used three kinds of activities – lecture, questioning during whole class lectures, and small group exam practice. Another teacher (Aishah) used four kinds of activities – lecture, questioning during whole class discussion, small group discussion after lab work, and one highly structured laboratory activity. The third teacher (Ali) used only two kinds of activities – lectures and questioning during whole class discussion.

The variety of teaching activities was very limited across teachers. Lectures and teacher-directed questioning dominated across the teachers. One teacher used one highly structured laboratory activity (Aishah). Only small group discussion activities appeared to have two types: exam practice (Aminah) or discussion of lab work (Aishah). No demonstrations, computer-based simulations, model building or any other kinds of teaching activities were evident.

The teaching activities were nearly all teacher-centered. Lectures were of course teacher centered. Whole-class discussion was driven by the teachers' questions and laboratory work was highly structured by the teacher. The small group discussion after lab work was mainly to make sure students had right conceptions of Archimedes' principle. The small group exam practice sessions mostly allowed students solve specified problems and report their answers directly so that the teacher could verify them.

None of the teachers used student-centered pedagogies though they attempted to use them a little, as when Aminah asked students to work in groups to discuss answers of questions that imitated national exam questions and when Aishah asked students to discuss the findings of their lab work. Given that the teachers all practiced teacher-centered pedagogy where they tightly structured lectures, questioning activities, small group discussion, and lab work, none of them used teaching activities that could be considered inquiry-based.

Overall, the teachers' teaching activities were generally teacher-driven. Given that many other possible teaching activities could be used like

demonstrations or constructing physical models, the teachers' teaching activities were limited as to type.

Multiple representations in practice and their translations. Using Lesh's Translation Model as a guide, the researcher analyzed all types of representations that the teachers used in practice and their translations, in order, in particular episodes. However, the analysis only focused on translations of modes of representations of Idea A and its associated ideas across the teachers. Idea A was selected because it is the central idea of Archimedes' principle that serves as a basis for other ideas. Table 9 shows the analysis of translations of representations for Idea A and associated ideas across the teachers.

Table 9

Translations of Representations of Idea A and Associated Ideas

Cases	Translations of Representations
Aminah	Episode 2: $WS_{a1} \rightarrow VS_{a1} \rightarrow RLS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1}$ Episode 4: $WS_{a1} \rightarrow F_{a1} \rightarrow VS_{a1} \rightarrow F_{a2} \rightarrow RLS_{a1} \rightarrow VS_{a2} \rightarrow P_{a1} \rightarrow VS_{a3}$ Episode 5: $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a2} \rightarrow VS_{s1} \rightarrow VS_{a3} \rightarrow RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a4}$
Aishah	Episode 3: $M_{a1} \rightarrow VS_{a1} \rightarrow VS_{a2} \rightarrow M_{a2} \rightarrow VS_{a3} \rightarrow VS_{s1} \rightarrow M_{a3} \rightarrow VS_{s2} \rightarrow WS_{s1} \rightarrow VS_{a4} \rightarrow VS_{s3} \rightarrow RLS_{a1} \rightarrow F_{a1} \rightarrow VS_{a5} \rightarrow VS_{s4} \rightarrow RLS_{b1} \rightarrow P_{b1} \rightarrow WS_{b1} \rightarrow VS_{a6} \rightarrow VS_{s5}$ Episode 6: $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$ Episode 8: $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$ Episode 9: $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$ Episode 10: $RLS_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4} \rightarrow WS_{s1}$ Episode 12: $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{s1}$ Episode 15: $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{s1}$ Episode 16: $VS_{a1} \rightarrow F_{a1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow VS_{a3} \rightarrow VS_{s3} \rightarrow F_{b1} \rightarrow VS_{a4} \rightarrow VS_{s4}$
Ali	Episode 2: $WS_{a1} \rightarrow RLS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1}$ Episode 6: $RLS_{a1} \rightarrow P_{a1} \rightarrow WS_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow WS_{b1} \rightarrow VS_{a2} \rightarrow VS_{s2} \rightarrow WS_{s1}$ Episode 9: $RLS_{a1} \rightarrow W_{a1} \rightarrow F_{a1} \rightarrow VS_{a1} \rightarrow VS_{s1} \rightarrow W_{s1}$ Episode 13: $RLS_{a1} \rightarrow V_{a1}$

Note. M: manipulative, VS: verbal symbols, WS: written symbols, P: pictures, F: formulae, RLS: real-life situations, subscripts of _s: student-generated representations, subscripts of ₁₋₉: the sequence of using a particular representation, subscripts of _{a-d}: representations came from two different sources, arrows \rightarrow : translations across and within modes of representations.

Based on Table 9, the first finding was that real-life situations (RLS) and formulae (F) representations were the key representations for teaching

Archimedes' principle. The real-life situations were presented as pictures –

actually diagrams. RLS and F were two representations that were usually placed at the beginning of the translations (episode 5 for Aminah, episodes 6, 8, 9, 10, 12, 15 for Aishah, and episodes 6, 9, 13 for Ali) or in the middle (episodes 2 and 4 for Aminah, episodes 3 and 16 for Aishah, and episode 2 for Ali). Pictures (P), written explanations and questions (WS), and verbal communication (VS) surrounded the RLS and F representations in teaching episodes of all teachers.

The second finding was that the representations that came from students were minimal. In all cases, the teachers primarily produced the six representations (RLS, F, P, WS, VS, and M) while students mainly produced VS representations and sometimes WS. This indicated that the representations and translations of the modes of representations were predominantly teacher-centered.

The third finding was that the translations of the representations varied greatly in length and complexity. Aishah had the longest translation and the most complex one while Ali had the simplest one. Aminah's translation was generally moderate. In episode 3, Aishah's inclusion of manipulative representations made the translation longer as compared to other teachers' translations because two other teachers did not use manipulatives. Aishah also conducted a dialogue with students and asked them to discuss in groups their investigation of the weight of liquid displaced. Many verbal (VS) and written (WS) representations were used during the dialogues and discussion regarding the manipulative activities. In Ali's case, he shortly explained Plimsoll lines used by ships in episode 13 – this

translation was the shortest one. He did not use other representations like pictures (P) or written symbols (WS).

The fourth finding was representations of graphs (G) and tables (T) were not evident in any of the cases. Aminah, Aishah, and Ali all did not use those two modes when teaching Idea A and the associated ideas of Archimedes' principle.

Overall, RLS and F representations played central roles in shaping the translations across modes of representations where they primarily acted as initiators and focus points of translations. The teachers' translations of representations were mainly teacher-driven and student-generated representations were few. Only one teacher adopted manipulative representations that made her translation the most complete one. Meanwhile, translations across modes were common across teachers. In sum, the teachers' translations of representations, in general, were not all-inclusive except for Aishah's. Not all of the teachers used manipulative representations that had limited their translations. The most striking finding was that the translations were almost entirely teacher-centered; thus the teachers' teaching of Archimedes' principle overall was teacher-centered, too. This finding was consistent with the analysis of the teachers' teaching activities that showed the dominant use of teacher-centered teaching activities.

Why Do Physics Teachers Teach Archimedes' Principle in the Ways They Do?

The construct of contextual knowledge (CxK) was primarily used to answer the second research question. Integrations of CxK with subject matter

knowledge (SMK) and pedagogical knowledge (PK) were present to provide reasons for the teachers' teaching practices. The main finding regarding the second research question was the significant roles of two national contextual amplifiers, the national curriculum and assessment, in shaping the teachers' pedagogical content knowledge (PCK) in practice.

The main ideas of Archimedes' principle and the national contextual amplifier. The teachers taught the same ideas of Archimedes' principle because all of them were required to teach content that is set by the national curriculum, a national contextual amplifier. Furthermore, the content is used as the basis for the Ministry of Education to construct the national exam questions regarding Archimedes' principle. The national exam was another national contextual amplifier. Archimedes' principle is one of the topics in the national curriculum. Hence, all of the teachers were compelled to teach Archimedes' principle and the four ideas of the principle.

In addition to the specification of the four ideas, all of the teachers indicated that they were required to finish teaching the national syllabus of physics as the means to prepare students for the national exam because the exam questions were constructed based on the learning objectives stated in the national curriculum. The same use of learning objectives was found across the teachers. Thus, the teachers taught the same ideas and used the same objectives as were required by the two national contextual amplifiers, the national curriculum and the national examination. The requirements of the national contextual amplifiers were

influential in the decisions about what to teach [Codes: AM-PREIN-June 23-5, AM-PREIN-June 23-22, & AM-POSTIN1-Aug 18-7, AI-PREIN-June 29-49, AL-PREIN-June 24-25, AL-PREIN-June 24-26, AL-PREIN-June 24-27, AL-POSTIN1-Aug 23-6, AL-POSTIN1-Aug 23-7, AM-DOCLP-July 27-4, AM-DOCSL-July 27-13, AM-DOCM-July 28-1, AM-DOCM-July 28-2, AM-DOCM-July 28-3, & AM-DOCM-July 28-4, AI-DOCM-Aug 17-12, AI-DOCM-Aug 24-4, AI-DOCM-Aug 24-5, AI-DOCM-Aug 24-6, DOCLP-July 22-1, AL-DOCLP-July 22-2, AL-DOCLP-July 22-5, AL-DOCPH-July 22-8, AL-DOCPH-July 22-9, AI-DOCM-Aug 24-7, AI-DOCM-Aug 17-16, AI-DOCM-Aug 24-1, & AI-DOCM-Aug 24-2].

Organization of the main ideas of Archimedes' principle and its association with the national amplifier. As mentioned in the previous section, the three teachers showed great differences in terms of their organization of the four main ideas in teaching practices. One reason was each teacher's order of teaching the ideas depended on their selection of teaching activities associated with the national curriculum recommendations. Table 7 shows that Aishah started teaching with Idea B. Based on teaching episodes in Chapter 4, she used lab work when starting her teaching (episode 2). Aishah did not teach the concept of Archimedes' principle first. She rather directly asked students to do lab work and did the investigation of the apparent loss of weight of an immersed object in water that is equal to the buoyant force, which is Idea B [Codes: AI-VOR-Aug 17-11 & AI-OBS-Aug 17-4]. This order was reasonable because data from the

investigation of Idea B would be used to investigate Idea A [Codes: AI-VOR-Aug 17-26 & AI-OBS-Aug 17-4].

On the other hand, Aminah and Ali started with Idea A, and they used lectures unlike Aishah did. Aminah and Ali did not conduct lab work like Aishah did. Aminah had mentioned during her teaching that she lectured on Idea A because the idea would be used to understand other ideas [Code: AM-DOCSL-July 27-10]. She first gave a brief lecture in episode 2 about Idea A and then provided a detailed lecture on Idea A in episode 4. In between episodes 2 and 4 (episode 3), she lectured on Idea B in relation to the previous idea, Idea A. Lecturing on Idea A in brief, then giving in-depth lectures on Idea B, and then providing detailed lectures on Idea A indicated that lectures could be useful to explicate the most general idea of Archimedes' principle in order for students to learn other related ideas. Use of lectures was feasible if the teachers started lectures with the most inclusive idea (Idea A) before teaching related ideas, Idea B, C, and D.

The nature of lab work and lectures seemed to shape the teaching of the first idea. Aishah's order was more like inductive teaching (from doing concrete learning like lab work to making abstraction of Archimedes' principle) because she did not directly teach students the whole idea of Archimedes' principle first. She instead started with manipulative activities, namely lab work that was more concrete. In the cases of Aminah and Ali, they lectured on the most inclusive idea first before teaching other related ideas and their teaching was more like

deductive teaching (from abstraction of Archimedes' principle to giving specific examples of Archimedes' principle). Aishah somewhat used a discovery learning approach while other two teachers used a more direct teaching approach.

The first idea that Aishah taught showed a consistency with the national curriculum recommendation on teaching activities where it suggests the teachers teach Idea B at the very beginning using lab work. The national curriculum then suggests the teaching of Idea A in relation to Idea B also by using lab work. Nonetheless, Aminah's and Ali's order was not consistent with the national curriculum recommendations because they did not use lab work. If they had conducted lab work as Aishah did, the three teachers would have shown the same order of teaching the first idea of Archimedes' principle.

Regarding the order of teaching all ideas, the previous section revealed that all teachers, except Ali, taught Ideas A and B before Ideas C and D. During lectures, Aminah told her students that Idea A (about the weight of liquid displaced) would be applicable for Idea C (flotation) and Idea D (submersion) [Codes: AM-VOR-July 27-5]. Idea A was the basic idea needed to understand Ideas C and D. Meanwhile, Idea B was essential for understanding the existence of a buoyant force [Codes: AI-OBS-Aug 17-6 & AI-VOR-Aug 17-18]. Hence, the reason for the order of teaching Ideas A and B before C and D was that Ideas A and B were fundamental while Ideas C and D were applications where an object would either float or sink at a time. The overall order that Aminah and Aishah used was consistent with the national curriculum recommendation that suggests

teachers to teach Idea B and Idea A before Idea C and Idea D, but Ali's use of that order was not evident.

In terms of combination of ideas, all three teachers combined Ideas C and D. The reason was all of them taught about submarines, a real-life situation representation of Archimedes' principle that applies Ideas C and D because submarines can function in dual situations, flotation (Idea C) and submersion (Idea D). The nature of real-life situation representation shaped the combination of ideas. In relation to this combination, the national curriculum requires teachers to teach application of Archimedes' principle and it specifically recommends teachers teach about submarines along with hot air balloons and hydrometers.

About emphasis of teaching the main ideas, all of the teachers emphasized Idea A and Idea C because Idea A was especially important in understanding other ideas. Aminah specifically told her students that the concept of the weight of liquid displaced (Idea A) would be used to comprehend flotation (Idea C) and submersion (Idea D) [Codes: AM-VOR-July 27-5]. For Idea C, all of the teachers taught applications of Archimedes' principle like boats, ships, submarines, and hot-air balloons that required applications of Idea C [Codes: AM-DOCM-July 28-2, AM-DOCM-July 28-4, AM-DOCSL-July 27-12, AM-DOCSL-July 27-13, AI-DOCM-Aug 24-9, AI-VOR-Aug 24-8, AL-VOR-July 22-15, AL-VOR-July 22-18 & AL-VOR-July 22-19].

This emphasis of Ideas A and C indicated that the teaching of the two ideas appeared to be essential and teaching them frequently implied their wide use

in understanding and applying Archimedes' principle in real-world situations. Teaching the concept (Idea A) and applications of Archimedes' principle (Idea C) was required by the national curriculum, and most of the applications recommended teaching the application of Idea C in the workings of submarines and hot-air balloons.

Overall, the three teachers' order of teaching the first idea of Archimedes' principle would depend on their selection of teaching activities. Their order would be the same if they followed the national curriculum recommendations regarding teaching activities. For the overall order of teaching the ideas, the three teachers would have a similar order of Ideas B, A, C, and D if they tallied their teaching with the national curriculum recommendations. In terms of combination of ideas, all of the teachers combined Ideas C and D due to the nature of a real-life situation representation, submarines. Regarding the emphasis of teaching the main ideas, the emphasis given to Ideas A and C indicated that the two ideas were crucial and widely used to understand the concept and applications of Archimedes' principle in real-world settings. The national curriculum requires the teachers to teach the concept (Idea A) and applications of Archimedes' principle that mostly apply to Idea C. Teaching them frequently would likely make students understand theoretical and practical parts of Archimedes' principle better.

Teaching activities and their connections with personal and contextual amplifiers and filters. The previous section revealed that the teachers all used teaching activities that were almost entirely teacher-centered, the variety

of the activities was limited to a certain range, and no inquiry methods were used. The teachers gave several reasons for using specific teaching activities and these were primarily from their personal and contextual amplifiers and filters. Table 10 shows the reasons for using particular teaching activities.

Table 10

Reasons for Using Certain Teaching Activities

Teaching Activities	Reasons	Cases		
		Aminah	Aishah	Ali
Lectures	To make students know keywords of Archimedes' principle that is essential for answering examination questions, and/or to finish teaching on time, and/or time constraints.	X	X	X
Questioning	To know students' existing knowledge and alternative conceptions in ideas of Archimedes' principle, and/or to prepare students for exams.	X	X	X
Lab work	This activity was useful for teaching a complex idea like Archimedes' principle, allowed students to engage with a manipulative type of learning through measurement of variables, to prepare students for taking Paper 3 of the national exam.		X	
Small group discussion	To encourage collaboration among group members, and/or prepare students for answering the national exam questions, and/or personal knowledge about the national assessment.	X	X	

From Table 10, it was evident that regardless of teaching activities, all of the teachers used them mainly to prepare students for the national exam. This was the primary finding regarding the reasons for using certain teaching activities. Even though the reasons were often the teachers' personal amplifiers, the national exam preparation, a national contextual amplifier, was the strongest reason because the current system of educational assessment is exam-oriented [Codes: AM-POSTIN1-Aug 18-19, AI-PREIN-June 29-4, AI-POSTIN1-Aug 30-17, & AI-POSTIN1-Aug 30-26, & AL-POSTIN1-Aug 23-42]. The national exam seemed to play a significant role in shaping the teachers' reasons for adopting particular teaching activities.

The second finding was about the types of teaching activities used and the teachers' freedom in relation to the national curriculum recommendations. Given that only one teacher used lab work and none of them built physical models, the teachers' teaching activities were not fully consistent with the national curriculum recommendations (Ministry of Education, 2005, pp. 29-30). In this regard, the teachers, especially Aminah and Ali, tended to ignore recommended teaching activities because the teachers were not required to use them. Thus, it reflected the fact that the teachers had freedom to choose any teaching activities that they deemed appropriate for their students.

In relation to the second finding, the teachers provided several reasons for not using lab work as recommended by the national curriculum. Ali mentioned that he faced time constraints to prepare for doing lab work due to a high

workload and he changed his mind and instead, used questioning activities with a pictorial representation of Archimedes' principle's investigation in episode 7 as a substitute [Codes: AL-POSTIN2-Aug 26-37, AL-POSTIN2-Aug 26-38, & AL-VOR-July 22-29]. In Aminah's case, she faced the problem of insufficient lab supplies, including outdated and rusted lab equipment, so she instead showed students a pictorial representation of Archimedes' principle's investigation just as Ali did in episode 3 [Code: AM-POSTIN2-Aug 22-31, AM-POSTIN2-Aug 22-32, AM-POSTIN2-Aug 22-33, AM-POSTIN2-Aug 22-34, & AM-POSTIN2-Aug 22-35]. These barriers were perceived school filters.

The perceived school filters seemed to impede the teachers' intention to conduct lab work. However, the alternatives they used like showing students a picture of investigation of Archimedes' principle indicated that they could have considered other choices of activities like demonstrating the phenomena of flotation, immersion, and the weight of water displaced using simple objects and materials like bottles, water, stones, coins, and floating objects like apples. They also could have considered building a physical model like Cartesian divers as recommended by the national curriculum. They, nonetheless, did not conduct such demonstrations or model building. Hence, it was reasonable to say that the teachers' repertoires of teaching activities in practice were limited, particularly Aminah's and Ali's.

Only one teacher, Aishah, conducted lab work. She had several reasons for using the teaching activity. In Table 10, she mentioned that lab work activities

were suitable for teaching a difficult topic like Archimedes' principle because lab work could help students see concretely the phenomena of the apparent loss of weight of an immersed object in a liquid and the liquid displaced. This was Aishah's personal amplifier regarding lab work. Even though Ali and Aminah did not conduct lab work, they had similar thoughts with Aishah about the usefulness of lab work for teaching Archimedes' principle [Codes: AM-POSTIN2-Aug 22-30, AI-POSTIN2-Sept 2-25, AL-PREIN-June 24-13, & AL-PREIN-June 24-58]. That said, all of the teachers knew that lab work was suitable for teaching Archimedes' principle effectively because it allowed students to manipulate apparatuses and materials like a Eureka can, beakers, loads, spring balance, and digital balance, and investigate and observe the phenomena of the loss of weight of an object in water and water displaced, the basic ideas of Archimedes' principle. These thoughts were teachers' unused personal amplifiers regarding lab work, specifically in Aminah's and Ali's cases.

Personal amplifiers also played roles in shaping the teachers' use of group work activities. Aminah's use of small group exam practice was associated with her personal amplifier about the current assessment system. She hoped that the assessment system to be more lenient allowing for adoption of school-based assessment [Codes: AM-PREIN-June 23-33]. A school-based assessment is now used for the lower secondary schools but the upper secondary assessment remains with the prime use of the national exam. A school-based assessment allows teachers to conduct group projects and presentations for students. In relation to

Aminah's case, she used small group exam practice, a group work activity, to teach students Archimedes' principle. She mentioned that the activity would make students collaborate with each other and further stated that, "if a student needed to modify an object like a car, he or she could not do it alone. They needed to work together in teams, which can modify a product better than when individuals work alone" [Codes: AM-POSTIN2-Aug 22-22 & AM-POSTIN2-Aug 22-23].

Aminah's personal amplifier about the need to change the current assessment system was associated with her use of small group exam practice because the group work fitted with the nature of group projects. The national exam is individual-based assessment and not group-based.

In comparison with other teachers' cases, Ali indicated a different personal amplifier about his use of questioning activities. Unlike Aminah, Ali did not want his students to work in groups to solve problems given to them because he mentioned to his students that they could not talk to each other during exams [Codes: AL-VOR-July 23-3 & AL-VOR-July 23-4]. Ali's personal amplifier indicated a consistency with the nature of exams that do not allow students to work together to answer questions.

Both Aminah and Ali provided students with questions that imitated the national exam questions. However, both of them used different teaching activities: small group work (Aminah) and questioning without group discussion (Ali). Ali's personal amplifier aligned with the nature of the national exam (a national contextual amplifier) that assessed students individually, but Aminah's did not

because she believed in the need to transform the national contextual amplifier. This finding indicated that the teachers' selection of teaching activities seemed to be influenced by their personal knowledge of the national contextual amplifier. A reform-like way of thinking about the national contextual amplifier appeared in Aminah's case that was associated with her pedagogical knowledge in practice specifically in the use of group work activities. As for the third teacher, Aishah, her personal amplifier regarding the national contextual amplifier was not evident.

Multiple representations in practice and their connections with contextual amplifiers and filters. The teachers used real-life situations (RLS) and formulae (F) representations as the initiators and focuses of translations because the national curriculum requires the teachers to teach students about the concepts of Archimedes' principle and its applications in the real world as the learning outcomes. In addition, the past national exam asked about the concepts and their applications. The concepts of Archimedes' principle included the formula of $F = \rho V g$ (Idea A) and other associated formulae of $F = mg$ (Idea C) and $F = W_1 - W_2$ (Idea B). All of these formulae simplified the concept of the apparent loss of weight of an immersed object in a liquid (Idea B), the concept of flotation (Idea C), and the concept of liquid displaced (Idea A). These formulae were useful especially for teaching students quantitative problems related to Archimedes' principle. For example, in episode 6 in Aishah's teaching, she provided students with a set of quantitative question related to Idea A and Idea B.

She asked students to solve the question and students were required to apply the formulae of $F = pVg$ (Idea A) and $F = W_1 - W_2$ (Idea B).

The past national exam asked questions related to the concepts of Archimedes' principle. For example, in year 2009, Paper 1 question number 18 asked students about the concept of flotation where a wooden block floats on water. The question required students to know the concept of flotation and apply the formula of $F = mg$ where the buoyant force (F) is equal to the weight of the wooden block (mg) (Ministry of Education, 2004, pp. 69). The teachers would be aware of these representations in these questions and thus were likely to employ such representations in their teaching activities.

Regarding RLS representations, the national curriculum also requires the teachers to teach applications of Archimedes' principle as one of the learning outcomes (Ministry of Education, 2005, pp. 30). The national curriculum suggests several applications like submarines, hot air balloons, and hydrometers. The teachers taught all of these applications.

The past national exam of physics also asked questions about applications of Archimedes' principle. For instance, in year 2010, Paper 2 question number 9(d), the question asked students about the application of rafts. Students were asked to "design a raft which can accommodate 15 people and be able to move quickly in water." This type of question was consistent with the questions that the teachers used in practice. For example, in Ali's case in episode 12, he provided a question about designing a boat that could have a great magnitude of buoyant

force and is safer. The question asked students to apply their knowledge about flotation (Idea C).

Overall, the teachers' translations of representations were mainly driven by the representations of RLS and F because of the requirements of the national curriculum and national exam to teach students about the concepts and applications of Archimedes' principle. The national curriculum and national exam both were the national contextual amplifiers. The consistency between the teachers' use of two primary modes of representations (RLS and F) and the national contextual amplifiers implied that the main direction of translating the representations was to fulfill the demands of the national contextual amplifiers.

About the domination of the teachers' tendency to translate multiple representations, the teachers highly structured the teaching activities where they generated the majority of the representations. Based on the translations of representations in Table 9, the teachers used a lot of verbal symbol (VS) representations because they talked a lot about RLS, F, and P. A substantial use of VS was linked to the teachers' use of lecturing and questioning activities where the teachers mostly talked about Archimedes' principle and led discussion with students. A strong association between representations and teaching activities was captured because representations used would greatly depend on how the teachers structured the teaching activities.

Regarding use of manipulative representations, one teacher, Aishah said she used them because Archimedes' principle was a hard topic for students to

understand. Using manipulatives would allow Aishah's students to see and investigate the ideas involved in that principle concretely. Aishah's use of manipulatives was consistent with the national curriculum recommendation that suggests teachers use lab apparatuses to teach Archimedes' principle.

In fact, however, Aishah and other two teachers did not use another manipulative representations, physical models, as suggested by the national curriculum. Physical models like a Cartesian diver mentioned by the national curriculum would allow students to understand flotation and submersion using tangible objects. Nonetheless, the teachers did not align their use of manipulative representations with the national curriculum recommendations. The national curriculum seemed to emphasize use of manipulative representations through lab work and building physical models but the teachers tended to ignore the recommendations. Insufficient use of manipulative representations had limited the teachers' translations of representations and thus made the translations incomplete.

Regarding representations of tables (T) and graphs (G), none of the teachers used those two modes. The reason was the nature of the topic of Archimedes' principle did not include the two modes. Referring to the national physics curriculum, the descriptions of teaching Archimedes' principle did not mention uses of graphs and tables. Other topics of physics like Ohm's Law could use the two modes because it explains the relationship of potential difference (V) and current (I) at constant temperature (Ministry of Education, 2006, pp. 25),

where a graph of V versus I could be made from a table of V versus T . Thus, in the context of Archimedes' principle teaching, representations of graphs and tables were not applicable.

Chapter VI: Themes, Discussion, Conclusion, and Recommendations

This study investigated Malaysian physics teachers' teaching practices from the perspective of pedagogical content knowledge (PCK) in practice. Two research questions were used:

- (1) How do physics teachers teach Archimedes' principle in real classroom settings?
- (2) Why do physics teachers teach Archimedes' principle in the ways they do?

Six themes were developed from the information presented in Chapter 5 to answer the two research questions. These themes are stated in terms of the integrative PCK framework (Gess-Newsome, 1999) that focused on the integration of subject matter knowledge (SMK), pedagogical knowledge (PK), and contextual knowledge (CxK) in practice. Originally, the themes were to be written for each of the seven areas of the PCK model. However, the results were not so easily categorized. The three types of knowledge were highly integrated in practice (e.g. SMK and PK or PK and CxK or SMK, PK, and CxK). There was no evidence that a theme would necessarily be self-contained within SMK or PK or CxK. The themes combined the answers to the research questions as they described how and why the teachers taught as they did. The themes are presented in roughly their order of importance. A brief discussion of each theme and relevant literature follows. Finally, recommendations for policy, practice, and

future research are proposed. These recommendations were important to show implications of this study to the three domains.

Themes and Discussion

Theme 1: The teachers' subject matter knowledge in practice included the teaching of the ideas that were based on a national contextual amplifier, the national curriculum. This theme presents one of the two most important findings. The national curriculum, a national contextual amplifier, required the teachers to teach all four ideas of Archimedes' principle. A uniformity of main content was observed in that all of the teachers taught the four main ideas: (1) Idea A – The weight of liquid displaced, (2) Idea B – The apparent loss of weight of an immersed object in a liquid, (3) Idea C – Flotation, and (4) Idea D – Submersion. The national curriculum shaped this uniformity because it required all of the ideas be taught.

The uniformity of content across the teachers indicated the effect of a highly standardized national curriculum (Kerckhoff, 2001). Stevenson and Baker (1991) found that teachers' mathematical content of teaching was less varied when they taught in a country with national controls on the curriculum. The results of this study aligned with Stevenson and Baker's finding but are even more dramatically. The present study shows no variation in the main ideas that were taught. The teachers in this highly centralized system taught exactly those specific ideas that were required by the national curriculum. This result is likely to

happen in other nations that practice highly centralized and standardized curriculum with a truly required curriculum.

The national curriculum could be another source of canonical PCK in addition to canonical science and learning theories as proposed by Park and Suh (2015). The national curriculum is standardized nationwide and becomes the main reference for content of teaching. The curriculum became canonical where all of the teachers needed to teach content of the curriculum. Inclusion of the construct of contextual knowledge, specifically the national contextual amplifier (the national curriculum) into the PCK model had expanded the current scope of canonical PCK that was otherwise limited to subject matter knowledge and pedagogical knowledge.

Theme 2: The teachers' pedagogical knowledge in practice included teacher-centered teaching activities that were strongly associated with a national contextual amplifier, the national assessment. This theme presents one of the two most important findings. All of the teachers used their primary teaching activities to prepare students for the national exam, a national contextual amplifier. Aminah used lectures and small group exam practice activities to teach students to answer questions that mimicked the national exam questions and taught them how to answer the questions according to the national exam requirements. For Aishah, she conducted lab work to prepare students for Paper 3 of the national exam, which is about planning an investigation of a physical phenomenon. In Ali's case, he conducted questioning during the whole class

discussion and provided students with questions that imitated the national exam questions like Aminah did. All of these teaching activities were teacher-centered because the teachers primarily lectured, led the questioning activities, highly structured the lab work, and mainly directed student groups' work.

The main reason for the teachers to teach students for exams was the current educational system of high school physics is exam-oriented. The teachers felt that they must prepare students for the exams, either at the school level or the national level. In this situation, the national exam is the main assessment driver because the school exams followed the national exam requirements and formats. Even though the national curriculum does not say anything about exams, the teachers could not ignore the purpose of teaching for the sake of making all students passed exams with good grades.

The fact that the national exam determines the students' educational and career paths after high school makes the national exam a high-stakes exam. Students that get a good exam score in physics can pursue education at a higher level, pre-university programs, and enroll in science programs as a cornerstone to continue education at the college level. Low exam scores eliminate this possibility.

The national exam was the main purpose of the teachers' teaching. The teachers' teacher-centered teaching practices did not align with the national curriculum recommendation that suggests teachers to use inquiry. With pressure from the system to ensure students achieve a good grade in a high-stakes exam,

use of an inquiry-based learning approach is not always a choice for practice among science teachers (Crawford, 2014; Halai, 2012) and they tend to use teacher-centered pedagogy (Au, 2007; Duit et al., 2014; Rubin & Kazanjian, 2011). In this study, none of the teachers used an inquiry-based approach for teaching Archimedes' principle. Even though Luan et al. (2010) found that many Malaysian science teachers moderately intended to use inquiry more than didactic teaching, their study did not investigate actual practices of teaching of the teachers. The current study provides a stronger finding where, in practice, science teachers did not use inquiry though they all (Aminah, Aishah, and Ali) wanted to use it.

The teachers had no choice but to fulfill the demand of teaching for purposes of helping students prepare for a high-stakes exam though not all of them liked this situation. One teacher, Aminah, mentioned that she desired to see a change in the national educational assessment system. She hoped that the assessment system could become more flexible and not as exam-oriented. Her aspirations should be considered thoughtfully.

Theme 3: The teachers' subject matter knowledge in practice included orders and combinations of ideas based on pedagogical knowledge in practice, their selection of teaching activities, and real-life situation representations. The first idea taught in practice was related to the teachers' use of laboratory work or lectures at the beginning of teaching episodes. Aishah started teaching with Idea B by using lab work to investigate the apparent loss of

weight of a submerged object in a liquid (Idea B). Then the next set of data on the weight of liquid displaced (Idea A) could be collected. Aminah and Ali started with lectures and began with Idea A. Aminah lectured her students on the fact that Idea A would be applicable for flotation (Idea C) and submersion (Idea D). The lecture was used to present Idea A first as the idea was thought to be fundamental and essential to the teaching of other ideas. In terms of combination of ideas, all of the teachers combined Ideas C and D when they taught one real-life situation representation, submarines, that functioned in dual situations, flotation (Idea C) and submersion (Idea D).

Aishah's order of teaching the ideas was consistent with what was necessitated by following the national curriculum recommendation of beginning with laboratory work (Ministry of Education, 2005) and the way Hewitt (2002), a well-known and respected textbook author, explains the phenomena of buoyancy. On the other hand, Aminah and Ali did not follow the national curriculum recommendation of learning activities and Hewitt's organization. In these cases, the use of lectures instead of the recommended laboratory work resulted in an organization of ideas that was not recommended. Recommended teaching activities and a recommended organization of ideas were not necessarily used in practice. In contrast, all the teachers combined ideas as was necessitated by the use of the required application, the submarine representation. If the national curriculum required the teaching of certain activities and representations instead

of making only recommendations, then the organization of the ideas that were taught might have been followed.

Theme 4: The teachers' pedagogical knowledge in practice included teaching activities based on personal amplifiers. Aminah conducted small group exam practice activities because she believed that students would be able to work better in groups than as individuals with regard to the nature of real-world work that requires teamwork like designing a boat. In Aishah's case, she conducted lab work because she believed that labs were suitable for helping students to understand a complex topic like Archimedes' principle. In fact other teachers believed the same, but this personal knowledge remained unused personal amplifiers in their cases. Ali conducted questioning based on individual student work because he mentioned to students that they cannot discuss answers during exams.

Comparing Aminah's and Ali's ways of teaching students to answer examination questions, both of them used different approaches: group or individual work. What Ali said to his students was true; the exams did not allow students to discuss answers and students needed to function individually. However, Aminah's thought was that it was better to allow students to discuss answers in groups. Aminah had a personal amplifier that was not the same as Ali's. Aminah wanted to see a change in the current assessment system while Ali's desire along that line was not evident. These personal amplifiers were

consistent with their practices. Aminah's personal amplifier was somewhat different from the current assessment system while Ali's was strongly associated.

The personal nature of the teachers' reasons indicated that they had freedom to choose specific teaching activities. Even though the educational system is highly centralized, the teachers were given the choice to use any teaching activities that they deemed suitable for their students. They were not restricted to use particular teaching activities because that was a teacher's privilege to decide best pedagogy.

The idiosyncratic nature of the teachers' amplifiers indicated that personal PCK existed along with canonical PCK (Park & Oliver, 2008; Smith & Banilower, 2015). The teachers' personal knowledge informed their selection of certain teaching activities. These instances of personal knowledge were personal amplifiers because they inspired the teachers to use specific teaching activities with substantial practice. This finding supported the assertion that teachers' personal knowledge base could shape their PCK in practice (Gess-Newsome, 2015) under the notion of teacher amplifier.

Theme 5: The teachers' pedagogical knowledge in practice included a limited use of teaching activities that were associated with perceived school filters. The teachers themselves recognized the usefulness of lab work for teaching Archimedes' principle. However, not all of them used the lab work. Aminah indicated that she had a problem with insufficient lab supplies. She instead used lectures and showed students a picture of an investigation of

Archimedes' principle related to Idea A and Idea B. In Ali's case, he could not conduct lab work because of time constraints due to a heavy workload and also a big class size. Therefore, Ali gave lectures instead and took the same approach that Aminah did by showing a picture of Archimedes' principle investigation.

The school filters are called "perceived" because while the teachers gave these reasons, when in fact, they might have had other reasons and they almost certainly could have made different choices. In fact, they did make other choices in that they used pictures to substitute for the use of actual lab work. That indicated that they had considered other possible choices when facing the barriers. The literature suggested the similar thing (Fernandez-Balboa & Stiehl, 1995; Rollnick, 2016) in that teachers in that study made efforts to get curricular materials from other places. That said the teachers might have used manipulatives or lab work using borrowed materials from other schools or they could have demonstrated lab work to students by using objects and materials like stones, sponges, water, and wood to show the phenomenon of buoyancy. Nonetheless, application of this possible teaching activity was not evident. Regarding the problem of time constraints due to a heavy workload in Ali's case, he had the choice to ask students to bring objects to learn about Archimedes' principle. This choice would not take the teachers' extra time. In terms of a big class size, the teachers could have considered using group work to ease facilitating students' lab work or he could have sought teaching assistants to help run the lab work.

Many Malaysian schools have been shown to have problems with lab supplies and large class sizes (Phang et al., 2014; Thomas & Watters, 2015). This study reached the same conclusion. However, the problems with school filters mentioned in Aminah's and Ali's cases should not be considered a definitive reason for not using lab work because they did have other possible choices as mentioned earlier. Many scholars have urged teachers to teach Archimedes' principle using lab work due to their benefits and usefulness (Heron et al., 2003) and considering that Archimedes' principle is a hard topic (Loverude et al., 2003; Mohd Salleh & Abdullah, 2008; She, 2002) that requires use of tangible objects to help students observe the phenomena of buoyancy concretely. The teachers themselves acknowledged the value of lab work for teaching Archimedes' principle. Hence, they should be able to translate their personal amplifier into practice by using any other means that would bring them closer to implementing lab work activities like doing demonstrations using low-cost materials.

Theme 6a: The teachers' pedagogical knowledge in practice included translations across representations based on required national amplifiers, real-life situations and formulae representations. The teachers' representations of real-life situations (RLS) and formulae (F) of Archimedes' principle were the key representations in practice. However, the teachers' RLS representations were mainly portrayed using pictorial (P) representations, and F representations were usually portrayed using written symbols (WS) representations. RLS and F representations played great roles in the teachers' translations of representations

because the teachers were required by the national curriculum to teach students about applications and concepts of Archimedes' principle. The teachers taught applications of submarines, ships, and hot-air balloons that represented the RLS. They also taught the concepts of Archimedes' principle using the formulae of $F = V\rho g$, $F = W_1 - W_2$, and $F = mg$. All of these formulae simplify the ideas of the weight of liquid displaced (Idea A), the apparent loss of weight of a submerged object in a liquid (Idea B), and flotation (Idea C) respectively.

The literature about Lesh's translation model (Lesh & Doerr, 2003) suggested that teachers should be able to translate all modes of representations. However, studies that use Lesh's model (e.g. Pal (2014)) did not suggest RLS and F as the central modes of representations in practice and they did not link this to the influence of contextual knowledge, specifically the national curriculum. This study extended the literature by suggesting that RLS and F were the major modes of representations due to the requirement for teachers to teach real-world applications and concepts of Archimedes' principle by the national curriculum. This finding showed a tight connection between subject matter knowledge (main ideas of Archimedes' principle), pedagogical knowledge (RLS and F representations) and contextual knowledge (the national curriculum, a national contextual amplifier).

Theme 6b: The teachers' pedagogical knowledge in practice included translations across representations that were teacher-centered. Though the teachers used RLS and F representations as the major modes, the analysis showed

that their use of verbal symbols (VS) representations was extensive. VS surrounded RLS and F representations and other modes as well: pictures (P), written symbols (WS) and manipulatives (M). The teachers dominated use of VS representations where they primarily lectured, led questioning activities, or controlled the group work activities. Student-generated representations were minimal. This pattern of translations was teacher-centered.

This finding about teacher-centered translations of representations concretely confirmed the finding regarding use of teacher-centered teaching activities. One reason for this consistency was the close connection between teaching activities and representations. When the teachers primarily led the teaching through questioning and lectures, the teachers used representations of VS as the main representation. That was why VS surrounded the RLS and F representations and other modes of representations for all teachers. A minimal participation of students in giving questions to the teachers was the reason student-generated representations were also minimal. Most of the time the teachers talked, students answered the questions and then the teachers gave feedback.

The tight connection between teaching activities and representations was the reason why this study decided to combine these two elements under the pedagogical knowledge (PK) construct. It was hard to separate these two elements. In fact, when Shulman (1986) originally conceptualized PCK, he used the words “explanations” and “illustrations” to indicate that teaching activities

like explanations or lectures could be associated with representations like illustrations or pictures. Association between teaching activities and representations suggested that changing teaching activities would transform use of multiple representations in practice and their translations.

Theme 6c: Insufficient use of manipulative representations was evident across the teachers. The association between teaching activities and representations was evident when Aishah was the only teacher who used manipulative (M) representations. The reason was she conducted lab work that allowed her students to manipulate apparatuses like Eureka can, loads, and spring balances. Aishah's translations were the most complex because she translated all modes of representations, except tables (T) and graphs (G) as representations that were not applicable for Archimedes' principle. However, none of the teachers used model-building activities like making Cartesian divers as recommended by the national curriculum.

The literature suggested the importance of using manipulative representations in teaching a difficult topic. Students became excited to learn when they manipulated physical objects, and use of manipulatives made it easier to learn a hard concept (Pal, 2014). The teachers' translations of representations were not complete because many of them ignored the recommendations of the national curriculum to use physical objects to show students flotation and submersion phenomena. If the national curriculum required teachers to conduct

model-building activities instead of recommending them, all of the teachers would likely use manipulative representations.

Theme 6d: Use of representations of tables and graphs were not evident. The nature of Archimedes' principle did not require uses of tables and graphs. Teaching Archimedes' principle did not require explanation about proportion, unlike other topics like Ohm's Law that explains the relationship between potential difference (V) and current (I). A table and graph of V versus I could be developed from the relationship of the V and I because "the current (I) in a circuit is directly proportional to the voltage (V) established across the circuit, and is inversely proportional to the resistance of the circuit" (Hewitt, 2002, pp. 441).

Referring to Lesh's translation model (Lesh & Doerr, 2003), tables and graphs are included, but the current study found that all teachers did not use those two modes. This finding suggested that the use of Lesh's translation model relied on the nature of a specific science topic like Archimedes' principle. That said Lesh's translation model could be seen as just a guide to plan representations that a teacher could use. Not all eight modes (graphs, tables, manipulatives, verbal symbols, written symbols, pictures, real-life situations, and formulae) would be necessary to use because it depends on the nature of a particular subject matter whether or not each is applicable.

This finding is important to show that representations used for teaching a specific science topic depended on the nature of that specific topic. If a researcher

investigates other topics like Ohm's Law, he or she may be very likely to find teachers use tables and graphs representations. Hence, pedagogical knowledge (types of representations) depends to some extent on subject matter knowledge (the nature of Archimedes' principle).

Conclusion

In sum, the teachers' content of teaching and their reasons for using specific teaching activities were mostly consistent with requirements of the national contextual amplifiers, the national curriculum and assessment. They taught specific ideas that the national curriculum required and they used questioning, lectures, lab work, and small group discussion to prepare students for the national exam. Their use of multiple representations also indicated that they emphasized translations of real-life situations and formulae representation because the national curriculum required the teachers to teach about applications and concepts of Archimedes' principle. Thus, the required national contextual amplifiers appeared to play a great role in shaping the teachers' PCK in practice.

Nonetheless, the teachers' organization of the main ideas of Archimedes' principle varied significantly due to their selection of teaching activities. The teachers' selection of teaching activities was not fully consistent with the national curriculum recommendations. Most of them ignored the recommendation for using lab work and none of them conducted physical model building activities. The national curriculum also recommends use of inquiry but none of the teachers used it. Meanwhile the teachers' use of representations indicated substantial

differences in terms of selection of types of representations and translations across and within modes of representations. Just one of them used manipulative representations that the national curriculum recommends.

Overall, these findings suggested that the teachers' followed what was required by the national curriculum and the demands of the national assessment. However, they had freedom in either adopting or ignoring the national curriculum recommendations. They were free to plan and teach according to their personal choices. In this situation, they had the power to carry out what they desired in light of the national curriculum. That said the national curriculum did not determine how they should teach as it was a teacher's privilege to make those decisions.

Recommendations for Policy, Practice, and Future Research

The recommendations that follow result from the study of three physics teachers in Malaysia. Adopting the recommendations would require that the adopter considered their situation to be like Malaysia's. This choice will be more warranted if subsequent studies yield results that are similar to the ones upon which these findings are based.

Policy recommendations. Knowing that all of the teachers taught students for exam preparation, changing the national exam formats and requirements (the national contextual amplifier) would likely change teachers' pedagogical knowledge (PK) in practice, and thus their PCK in practice. The Ministry of Education could consider adopting a new assessment system that is

less exam-oriented for the upper secondary schools. The new assessment system could be able to promote student-centered pedagogy by using multiple modes of assessment like oral tests, projects, practical tests, and written tests. Knowing that the ministry had adopted school-based assessment for lower secondary education, they could extend the use to the upper secondary education. This action would soften the demands of preparing students for the national exam, and teacher's PCK in practice would likely be transformed.

Given that the teachers usually followed what was required but did not necessarily follow what was recommended, changing what is required vs. recommended in the national curriculum would be likely to change the teachers PCK in practice. Thus, the second recommendation is that the national curriculum requires rather than just recommending specific teaching activities like lab work and model building and representations like manipulatives. This change could be designed in a way that requires inquiry-based teaching.

The third recommendation has to do with school filters. First, school administrators and the Ministry should ensure that teachers have enough curricular materials and equipment for all students, especially laboratory tools to conduct lab work. Second, school administrators should find ways to reduce the large number of students in each classroom or they may employ teaching assistant to help teachers conduct lab work, model building activities and discussion. Third, they also should ensure that teachers have more time to plan and implement teaching rather than perform non-teaching tasks. School administrators need to

review teachers' workloads. These actions could enhance teachers' PCK in practice because many of them wanted to use lab work in a conducive situation, namely, having a smaller number of students, enough lab supplies, and more time for planning and conducting lab work.

The above recommendations are based on the assumption that the Ministry can and should seek as complete control of the pedagogical content knowledge in practice as possible. In any case, the Ministry could make significant changes ranging from (1) a broadly based decentralization of the system to (2) encouraging teachers to build some personal physics curriculum as supplementary to the standardized national curriculum, and from (3) the current approach of using requirements and recommendations of the national curriculum to (4) using very specific requirements. Encouraging teachers to develop some of their own curriculum might be best direction to take in the long run. Through professional development support for teachers, developing personal physics curriculum could enhance teachers' knowledge of subject matter and broaden teachers' freedom in choosing teaching activities that they deemed suitable for students, diversify ideas about teaching a specific science topic like buoyancy, and allow the teachers to customize what they do to their students' personal context. Following this idea is not a recommendation that follows directly from the results of this study, but these possibilities are presented here as a way of framing discussions on how to apply the results of the study in reforming the education system. Central to such

discussions would be the question of what requirements and recommendations are possible and which are the most widely desired.

Practice recommendations. Several recommendations emerge for teaching practice including teacher education. First, professional development providers such as colleges and universities and school administrators could design professional development programs for teachers to use inquiry teaching including student-centered lab work, manipulative representations, and active discussions among students. This action would be an important step forward in an effort to enhance teachers' pedagogical knowledge in practice.

Second, science teacher educators could use the findings of this study to show preservice teachers the reality of school science teaching in a highly centralized education system. Teacher educators could tell them that under the current system they still have freedom to shape their own teaching practices, especially pedagogical knowledge though the content of teaching is already set at the national level. That means they could diversify their teaching activities and representations as needed to broaden their pedagogical knowledge in practice. It is important to tell future science teachers that they have power to select suitable teaching activities and representations for their students because it is a privilege of a teacher to do that. Of course, this recommendation would be altered by changes the Ministry might make to require more and recommend less.

Future research recommendations. The first recommendation would be to continue the use of the research approach taken in this study with some extra

considerations. Using the integrative PCK model along with pursuing suggestions of scholars to examine PCK in practice led the researcher to seek information regarding the teachers' subject matter knowledge (SMK), pedagogical knowledge (PK), contextual knowledge (CxK), and integrations among those types of knowledge. The approach was productive in that it brought out specifics about PCK in practice that were previously typically unexplored.

Nonetheless, the researcher felt that it was truly hard to describe the teachers' knowledge in terms of single constructs (e.g. subject matter or pedagogical or contextual knowledge only) because the teachers' knowledge bases in practice were highly integrated. This phenomenon of knowledge integration indicated that the model of integrative PCK needs revision in terms of its use, especially when it comes to practice. The main feature of integrative PCK model, "each knowledge base must be well structured and easily accessible" (Gess-Newsome, 1999, pp. 13), seemed not to be pertinent in the teachers' actual practice. Redefining the integrative PCK model and matching it with the transformative model one would be preferred. This is because the transformative model suggested that the knowledge bases (SMK, PK, and CxK) are integrated and each knowledge base is latent in practice. The key issue would be to moderate the debate on the knowledge versus practice nature of PCK so that the knowledge part of PCK remains, but its translation into practice is essential. Future studies should conduct PCK studies that connect knowledge and practice of science teachers, not just their knowledge or practice. Complexity in analyzing teachers'

PCK knowledge and practice is expected because PCK itself is a vague notion as PCK scholars had mentioned.

Another change would be to use more differentiated forms of contextual knowledge. National, school, and personal contexts were found to be useful in this study. For future studies, they might include community contexts that likely could shape the teachers' PCK in practice especially when teachers teach students with diverse backgrounds in terms of race, religion, and socioeconomic status of students' families. This study did not examine students' characteristics or backgrounds. Investigating students' contextual factors may enrich perspectives of PCK in practice.

Furthermore, more refined meanings of the terms amplifier and filter are needed. In addition, the use of the terms needs to recognize that whether or not a particular contextual factor is an amplifier or filter depends on the specifics of the situation. In one situation, a factor can be an amplifier and in another it can be a filter. Furthermore, an amplifier can simultaneously serve as a filter. For example, in this study, the national curriculum was an amplifier in that it determined what teachers taught, but at the same time it would have excluded or filtered out the possibilities for teaching other ideas, and in that sense, it also served as a filter.

Moreover, this study defined real-life situation (RLS) representations as uses of Archimedes' principle in real-world settings like submarines, ships, and hot-air balloons. However, the researcher faced the dilemma to certainly define RLS representations because it could also mean teachers show and students see

concrete applications of Archimedes' principle where teachers might be able to bring students to places like a river or harbor that can show real submarines or ships. Thus, future studies could consider defining RLS representations as showing and seeing the actual applications of Archimedes' principle in real places.

The researcher acknowledged some limitations of this study that need to be addressed. Future studies should consider the following recommendations. First, future studies should use video recordings instead of just voice recordings and instructional materials. This study primarily used voice recordings that then restricted the researcher from showing the teachers their teaching episodes. Showing teachers videos of their teaching episode by episode could give them the opportunity to provide reflections of their teaching and elicit more about the teachers' PCK in practice, especially about their reasons for their decisions. Doing so will no doubt provide challenges of data analysis and data reduction but understanding the intricacies more completely may prove fruitful.

Second, future studies could recruit more participants to diversify the perspectives about PCK in practice. This qualitative study only had three participants, rendering it a small-scale study with limited generalizability. In relation to this recommendation, future studies could also use a quantitative approach to describe PCK in practice. Combination of qualitative and quantitative approaches is preferred. Quantitative approaches could be used to confirm

findings of small-scale studies like one that was used in this study so that generalizability of the findings would be widened.

Third, future studies could consider separate personal and contextual amplifiers and filters into different constructs of contextual knowledge. This study combined these two types of amplifiers and filters. Separating them could make a clear distinction between external and internal factors.

Fourth, researchers from other nations are encouraged to do research on PCK in practice in their respective countries and take into account the educational settings that could serve as contextual knowledge of science teachers. Countries that do not practice centralization of curriculum and assessment would likely produce research findings different than this study's. Thus, more studies are needed to see differences of PCK in practice across nations.

Final Remarks

Overall, this study provided insight about the teachers' PCK in practice "as it is." The findings are valuable to inform scholars, inservice teachers, teacher educators, preservice teachers, and Ministries of Education regarding the nature of PCK in practice in a highly centralized education system in a developing country. The specific nature of this study could help readers to characterize teachers' PCK in practice by linking practice with knowledge. Previous studies about PCK in practice incorporating consideration of contextual knowledge were typically uncommon. Including contextual knowledge into PCK constructs revealed significant controls of contextual amplifiers in influencing teachers' PCK in

practice. Hence, this study contributes to advancing the area of science teacher knowledge and practice.

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Appendix A

Pre-Teaching Interview Protocol

1. What are your goals when you teach physics? Why have you set those goals?

Apakah matlamat atau tujuan anda dalam mengajar subjek Fizik?

Boleh anda terangkan apakah sebab anda meletakkan matlamat atau tujuan tersebut?

2. What do you want students to learn?

Apakah yang anda mahukan murid untuk belajar Fizik?

3. How do you usually do your teaching? Why?

Bagaimanakah, kebiasaannya anda mengajar Fizik? Mengapa?

4. What other ways of teaching do you use? Why?

Apakah cara lain mengajar Fizik yang anda gunakan? Mengapa?

5. How do you assess the students' learning? Why?

Bagaimanakah anda mentaksir/menilai pembelajaran murid anda?

Apakah yang menyebabkan anda mentaksir/menilai dengan cara tersebut?

6. Do national policies, practices and guidelines influence what you teach? If so, how do they influence you? Why do these policies, policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan nasional (Kementerian Pendidikan)

mempengaruhi apa yang anda ajar kepada murid?

Jika ya, bagaimanakah hal tersebut mempengaruhi apa yang anda ajar?

Mengapakah polisi, praktis, atau panduan nasional itu mempengaruhi apa yang anda ajar kepada murid?

7. Do national policies, practices and guidelines influence how you teach? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan nasional (Kementerian Pendidikan) mempengaruhi bagaimana anda mengajar Fizik?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara anda mengajar Fizik?

Mengapakah polisi, praktis, atau panduan nasional itu mempengaruhi cara anda mengajar Fizik?

8. Do national policies, practices and guidelines influence how you assess students' learning? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan nasional (Kementerian Pendidikan) mempengaruhi bagaimana anda mentaksir pembelajaran Fizik untuk murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi apa yang anda taksirkan itu?

Mengapakah polisi, praktis, atau panduan nasional itu mempengaruhi apa yang anda taksirkan dalam pembelajaran Fizik murid?

9. Do school policies, practices and guidelines influence what you teach? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan pihak sekolah anda mempengaruhi apa yang anda ajarkan Fizik untuk murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi apa yang anda ajarkan itu?

Mengapakah polisi, praktis, atau panduan pihak sekolah itu mempengaruhi apa yang anda ajar kepada murid?

10. Do school policies, practices and guidelines influence how you teach? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?

*Adakah polisi, praktis, mahupun panduan pihak sekolah mempengaruhi **cara** anda mengajar Fizik?*

*Jika ya, bagaimanakah hal tersebut mempengaruhi **cara** anda mengajar Fizik?*

*Mengapakah polisi, praktis, atau panduan pihak sekolah itu mempengaruhi **cara** anda mengajar Fizik?*

11. Do school policies, practices and guidelines influence how you assess the students' learning? If so, how do they influence you? Why do these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan pihak sekolah mempengaruhi bagaimana anda mentaksir pembelajaran Fizik untuk murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara pentaksiran anda itu?

Mengapakah polisi, praktis, atau panduan pihak sekolah itu mempengaruhi apa yang anda taksirkan itu?

12. Do your students influence what you teach? If so, how do they influence you?

Why do students influence you in these ways?

Adakah murid-murid anda mempengaruhi apa yang anda ajarkan Fizik untuk mereka?

Jika ya, bagaimanakah hal tersebut mempengaruhi apa yang anda ajar itu?

Mengapakah murid anda mempengaruhi apa yang anda ajar kepada mereka?

13. Do students influence how you teach? If so, how do they influence you? Why

do the students influence you in these ways?

Adakah murid-murid mempengaruhi cara anda mengajar Fizik?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara anda mengajar

Fizik?

Mengapakah murid anda mempengaruhi cara anda mengajar Fizik?

14. Do students influence how you assess students' learning? If so, how do they

influence you? Why do the students influence you in these ways?

Adakah murid anda mempengaruhi cara anda mentaksir pembelajaran Fizik murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara pentaksiran anda itu?

Mengapakah murid anda mempengaruhi apa yang anda taksirkan pada pembelajaran Fizik murid anda?

Appendix B

Post-Teaching Interview I Protocol

1. What were your goals when you taught Force and Pressure unit? Why did you set those goals?

Apakah matlamat atau tujuan anda mengajar unit Daya dan Tekanan?

Mengapakah anda menetapkan matlamat itu sedemikian rupa?

2. What did you want students to learn about this unit?

Apakah perkara yang anda mahu murid untuk mempelajari unit ini?

3. Describe how you did your teaching about Force and Pressure unit? Why did you teach that way?

Bolehkah anda terangkan bagaimana anda mengajar unit itu?

Mengapakah anda mengajar sedemikian cara/pendekatan?

4. Did you assess what the students learned about Force and Pressure unit? How did you do that?

Adakah anda mentaksir apa yang telah murid pelajari dalam unit Daya dan Tekanan?

Bagaimanakah cara anda mentaksir pelajaran unit Daya dan Tekanan murid anda itu?

5. Did national policies, practices and guidelines influence what you taught about Force and Pressure unit? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan nasional (Kementerian Pendidikan) mempengaruhi apa yang anda ajar kepada murid dalam unit Daya dan Tekanan?

Jika ya, bagaimanakah hal tersebut mempengaruhi apa yang anda ajar?

Mengapakah polisi, praktis, atau panduan nasional itu mempengaruhi apa yang anda ajar kepada murid untuk unit ini?

6. Did national policies, practices and guidelines influence how you taught about Force and Pressure unit? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan nasional (Kementerian Pendidikan) mempengaruhi bagaimana anda mengajar unit Daya dan Tekanan?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara anda mengajar unit tersebut?

Mengapakah polisi, praktis, atau panduan nasional itu mempengaruhi cara anda mengajar unit ini?

7. Did national policies, practices and guidelines influence how you assessed students' learning about Force and Pressure unit? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan nasional (Kementerian Pendidikan) mempengaruhi bagaimana anda mentaksir pembelajaran unit Daya dan Tekanan untuk murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi apa yang anda taksirkan itu?

Mengapakah polisi, praktis, atau panduan nasional itu mempengaruhi apa yang anda taksirkan dalam pembelajaran unit ini untuk murid anda?

8. Did school policies, practices and guidelines influence what you taught about Force and Pressure unit? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan pihak sekolah anda mempengaruhi apa yang anda ajar bagi unit Daya dan Tekanan untuk murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi apa yang anda ajarkan itu?

Mengapakah polisi, praktis, atau panduan pihak sekolah itu mempengaruhi apa yang anda ajar kepada murid untuk unit ini?

9. Did school policies, practices and guidelines influence how you taught about Force and Pressure? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan pihak sekolah mempengaruhi cara anda mengajar unit Daya dan Tekanan?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara anda mengajar unit itu?

Mengapakah polisi, praktis, atau panduan pihak sekolah itu mempengaruhi cara anda mengajar unit tersebut?

10. Did school policies, practices and guidelines influence how you assessed the students' learning about Force and Pressure? If so, how did they influence you? Why did these policies, practices and guidelines influence you in these ways?

Adakah polisi, praktis, mahupun panduan pihak sekolah mempengaruhi bagaimana anda mentaksir pembelajaran unit Daya dan Tekanan murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara pentaksiran anda itu?

Mengapakah polisi, praktis, atau panduan pihak sekolah itu mempengaruhi perkara yang anda taksirkan itu?

11. Did your students influence what you taught about Force and Pressure? If so, how did they influence you? Why did students influence you in these ways?

Adakah murid-murid anda mempengaruhi apa yang anda ajarkan murid anda dalam unit Daya dan Tekanan?

Jika ya, bagaimanakah hal tersebut mempengaruhi perkara yang anda ajar itu?

Mengapakah murid anda mempengaruhi perkara yang anda ajar kepada mereka?

12. Did students influence how you taught about Force and Pressure? If so, how did they influence you? Why did the students influence you in these ways?

Adakah murid-murid anda mempengaruhi cara anda mengajar unit Daya dan Tekanan?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara anda mengajar unit itu?

Mengapakah murid anda mempengaruhi cara anda mengajar unit tersebut?

13. Did students influence how you assessed the students' learning about Force and Pressure? If so, how did they influence you? Why did the students influence you in these ways?

Adakah murid anda mempengaruhi cara anda mentaksir pembelajaran unit Daya dan Tekanan untuk murid anda?

Jika ya, bagaimanakah hal tersebut mempengaruhi cara pentaksiran anda itu?

Mengapakah murid anda mempengaruhi apa yang anda taksirkan pada pembelajaran unit Daya dan Tekanan murid anda?

Appendix C

Post-Teaching Interview II Protocol

Aminah

1. Why did you teach together Pascal's Principle, Archimedes' Principle, and Bernoulli's Principle in the same instructional time?

Mengapa anda mengajar Prinsip Pascal, Archimedes, dan Bernoulli secara bersama dalam satu masa pengajaran yang sama?

2. In my note, I did not see you used experiment when teaching Archimedes' Principle. Could you tell me what was the possible challenge of not using this method?

Dalam catatan saya, saya tidak melihat anda menggunakan eksperimen ketika mengajar Prinsip Archimedes. Bolehkan anda memberitahu saya halangan yang mungkin kepada penggunaan kaedah ini?

3. When teaching the topic of Archimedes' Principle and Bernoulli's Principle, you used the method of group discussion. What was the reason for using this method?

Ketika mengajar topik Prinsip Bernoulli, anda menggunakan kaedah perbincangan kumpulan. Apakah sebab anda menggunakan kaedah ini?

4. When using the group discussion method in the topic of Archimedes' Principle and Bernoulli's Principle, you also used questions that required multiple understandings on several topics, like Archimedes' Principle and Bernoulli's Principle. Why did you choose that type of question?

Kalau merujuk kepada jenis soalan yang diberikan kepada setiap kumpulan tu, saya lihat soalan2 tu berbentuk gabungan Prinsip Archimedes dan Bernoulli tu. Mengapa puan memilih soalan berbentuk sebegini?

Ali

1. In my note, I saw that you used an explanation method for teaching Archimedes' Principle. How did you think that this method was suitable?
Dalam catatan saya, anda menggunakan kaedah penerangan bagi mengajar Prinsip Archimedes. Bagaimanakah anda berfikir ianya sesuai?
2. I found that you did not use the method of experiment when teaching the topic of Archimedes' Principle. Could you tell me why?
Saya dapati anda tidak menggunakan kaedah eksperimen ketika mengajar Prinsip Archimedes. Bolehkah anda nyatakan mengapa?
3. In my note, you used open response questions regarding hot air balloon, submarine, and boat. Why did you choose those types of questions?
Dalam catatan saya, tuan mengedarkan soalan berbentuk respon terbuka ya seperti merekabentuk belon udara, kapal selam mahupun bot. Jadi, mengapa tuan memilih soalan berbentuk sebegini?
4. When using these kinds of questions, how did you see the difference with calculation type of questions?
Kalau melihat jenis soalan respon terbuka ini, bagaimana tuan melihat kelainan bentuk soalan sebegini dengan soalan berbentuk pengiraan?

Aishah

1. I saw that you continuously used the questioning method when teaching all topics in Force and Pressure unit. Could you explain why?

Saya dapati anda secara berterusan menggunakan kaedah penyoalan ketika mengajar semua topik Daya dan Tekanan. Bolehkah anda terangkan mengapa?

2. With regard to higher order questions that you used, how did you see this type of question was appropriate for teaching?

Kalau kita merujuk kepada jenis soalan beraras tinggi, jadi dalam konteks tekanan dalam cecair bagaimana puan melihat kesesuaian bentuk soalan ini?

3. When using these kinds of questions, how did you see the difference with calculation type of questions?

Kalau melihat jenis soalan respon terbuka ini, bagaimana tuan melihat kelainan bentuk soalan sebegitu dengan soalan berbentuk pengiraan?

4. Based on my note, I saw that you used the experiment method when teaching Archimedes' Principle. Why did you think that the method might be suitable for students?

Berdasarkan catatan saya, saya dapati anda menggunakan kaedah eksperimen bagi mengajar Prinsip Archimedes. Bagaimana anda fikirkan yang kaedah ini mungkin bersesuaian dengan murid?