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## Developing a Four-level Learning Progression and Assessment for the Concept of Buoyancy

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### ABSTRACT

Despite its complexity in science, sinking and floating is a phenomenon about which students of almost all grades develop personal theories, using a variety of conceptual elements such as weight, volume, shape, and density, prior to classroom teaching. Here, we distribute students from elementary to high school according to the levels of their achievement on the learning progression regarding the buoyancy phenomenon. We suggest four levels of learning progression for buoyancy concept. We developed a 13-item, open-ended, and short essay type questionnaire to evaluate students' learning progression of buoyancy concept based on two different contexts. We evaluated the validity and reliability of the new instrument for measuring buoyancy learning progression using a series of rigorous statistical tests. Participants of this study were students in grades 3-12 ( $N = 1,017$ ). A series of analyses including internal consistency analysis (Cronbach alpha), confirmatory factor analysis using structural equation modeling, and Rasch analysis for item fit and person/item reliability revealed that the instrument met the quality benchmark. Furthermore, our findings revealed that students' abilities in two different contexts were differentiated. Finally, we discuss the four levels of learning progression, concept assessment items developed, and some implications based on the findings.

**Keywords:** learning progression, buoyancy concept, concept inventory, Rasch model, cross-sectional study

### INTRODUCTION

Studies on the development of students' conceptual understanding have expanded to the examinations of learning progression. Learning progression is a developmental pathway in which students' understanding of science concepts and their ability to perform scientific inquiry become more sophisticated over a long period of time (Corcoran, Mosher, & Rogat, 2009; Duschl, Schweingruber, & Shouse, 2007). Since the process of forming a scientific concept is complex and can vary depending on various factors, such as teaching methods and prior knowledge,

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#### State of the literature

- Studies on the development of students' conceptual understanding have expanded to the examinations of learning progression.
- Learning progression studies in science education have been conducted in order to develop theoretical framework of students' learning progression steps and the assessments to identify students learning progression.
- Previous studies have indicated the need for study on learning progression of the buoyancy concept, which is an exemplary phenomenon that almost all grade students develop personal theories to explain prior to entering the science classroom.

#### Contribution of this paper to the literature

- In this study, a construct map and assessment items of students' accounts of buoyancy based on theory and previous studies were developed and evaluated in terms of validity and reliability.
- Students' learning progression of buoyancy concept between 3<sup>rd</sup> - 12<sup>th</sup> years was identified empirically by using various statistical methods such as Rasch modeling and confirmatory factor analysis.
- The contextual effect on the learning progression of buoyancy concept was found between two different contexts of buoyancy; one is the context of floating of various objects and the other is the mutual relationship between two objects in water.

learning progression can be called a hypothesis or estimation (Alonzo & Steedle, 2009). The learning progression can be a useful reference for teaching strategies because it provides a student's conceptual development pathway (Stevens, Delgado, & Krajcik, 2010). Science educators and researchers have thus become increasingly and rapidly interested in learning progressions. While there certainly are grounds for believing that learning progressions have the potential to transform science teaching, learning, and assessment, strong caution is advised. (Alonzo & Steedle, 2009).

Several learning progression studies have been conducted in science education. In a study of students' learning progression in life science, five learning progressions have been studied in molecular genetics. For example, in Roseman, Caldwell, Gogos, & Kurth (2006), molecular genetics concepts were built upon each other, increasing in sophistication. Duncan, Rogat, & Yarden (2009) investigated 5<sup>th</sup>-10<sup>th</sup> grade students' understandings of modern genetics and suggested a loose mapping of levels onto the following grade bands: 5<sup>th</sup>-6<sup>th</sup> grades (level 1), 7<sup>th</sup>-8<sup>th</sup> grades (level 2), and 9<sup>th</sup>-10<sup>th</sup> grades (level 3). Dougherty (2009) focused on concepts for middle/high school students, while Elmesky (2013) focused on concepts for grades K-12<sup>th</sup> grades. Todd and Kenyon (2015) suggested revisions to four of the eight constructs in Duncan et al.'s (2009) molecular genetics learning progression. Besides the molecular genetics concept, learning progression studies in the field of life science have also been conducted on the concept of biodiversity and ecosystem. Examples include the study on the development of complex thinking about biodiversity (Songer, Trinh, & Killgore, 2009); a sketch of the changes in Kindergarteners' representational and modeling practices about the concept of change, variation, and ecosystem (Lehrer & Schauble, 2012); an interpretation of student responses to a multiple-choice classroom assessment linked to a learning progression for natural selection (Furtak, Morrison, & Kroog, 2014); and a study on evaluating arguments to present evidence about knowledge of ecology (Gotwals & Songer, 2013). Gotwals and Songer (2013) conducted a dual-pronged validity study using a think-aloud protocol and an item difficulty analysis. They argued that the learning progressions could be used to link curriculum, assessment, and professional development to provide students and teachers with a coherent experience. They also suggested that validity studies were an important component of the work necessary to gather empirical evidence on the challenges associated with fostering and assessing students' knowledge development.

In earth and space science progression, Plummer and Krajcik (2010) presented a learning progression framework of students in grades 1, 3, and 8, analyzing the structure of astronomy education and how children learn to describe and explain the apparent patterns of celestial motions. Plummer (2014) developed a learning

progression framework for 3<sup>rd</sup> graders to explore the celestial motions. Plummer and Maynard (2014) developed the learning progression for 8<sup>th</sup> graders' reasoning about the seasons and proposed a construct map consistent with the Framework for K-12 Science Education (National Research Council, 2012). Plummer, Palma, Flarend, Rubin, Ong, Botzer, & McDonald (2015) illustrated the process of defining a hypothetical learning progression model for learning astronomy concept of solar system formation.

Mohan, Chen, Anderson (2009) proposed a learning progression for carbon cycling in socio-ecological systems for students in grades 4–12. Jin & Anderson (2012) suggested a learning progression framework for energy in socio-ecological systems. Their study was based on an assessment system developed by the Berkeley Evaluation and Assessment Research (BEAR) Center (Wilson, 2009) and on a previous study by Mohan et al. (2009). Data were collected from students in elementary, middle, and high school through written tests and clinical interviews. The methodology of Jin and Anderson's (2012) study was used by many others on learning progression. Using a similar method, Gunckel, Covitt, Salinas, & Anderson (2012) conducted a learning progression study on the concept of water in socio-ecological systems, targeting citizen participation in handling prevalent water problems. Their findings suggested that some changes in the curriculum, assessments, and interventions could be conducted to distinguish students' performances into four levels. Jin, Zhan, & Anderson (2013) developed a five-level, matter-and-energy learning progression framework for student understanding of carbon-transforming processes. Neumann, Vierung, Boone, & Fischer (2013) developed a learning progression of energy through energy form, energy sources, energy transformation, and energy conservation. Mayes, Forrester, Christus, Peterson, Bonilla, & Yestness (2014) investigated the ability of middle and high school students to engage in quantitative reasoning within the context of environmental science. Hokayem, Ma, & Jin (2015) examined how feedback constitutes loop reasoning, the main component of systems thinking, used by elementary students for the reasoning of interactions among organisms in ecosystems.

In physical science progressions, Alonzo and Steedle (2009) described an iterative process for developing a force and motion learning progression for 7<sup>th</sup> graders and the associated assessment items. Fulmer (2014) scrutinized the validity of two proposed learning progressions on the concept of force. Fulmer's study is the pioneering learning progression research that simultaneously compares middle school students' performance on force and motion concept with that on Newton's third law. In addition, Fulmer et al. (2014) further examined the force and motion learning progression comprising both one- and two-dimensional conditions of the content, but it was focused on different subjects for high school and university students.

Studies on the learning progression of matter have focused primarily on the development of students' notion about small particles. Wisner, Smith, Doubler, & Asbell-Clark (2009) examined the thinking of students aged 8–11 years (i.e., in grades 3–5) with a special focus on their development of concepts about matter's characteristics. They focused on two general advances that would lay the foundations for the atomic theory of matter. Stevens, Delgado, & Krajcik (2010) advanced a multi-dimensional hypothetical learning progression for the improvement of 7<sup>th</sup> to 14<sup>th</sup> graders' models of the structure, behavior, and properties of matter, as it relates to atomic structure and inter atomic interaction, electrical forces. A limitation of the research, however, was that the size of the sample was small and limited to specific grades and classes. Johnson and Tymms (2011) suggested a large-scale, cross-sectional study using Rasch modeling to test the hypothesis of the learning progression related to the concept of a substance. Chiu and Wu (2013) conducted research on student learning progression for the concepts of phase transitions, resultantly developing two-tier, multiple-choice questions for the concept of particle nature and phase transitions. Phylogenetic analysis using parsimony was used to compute and reconstruct the hypothesis of conceptual development.

### **Learning Progression of Buoyancy**

Inhelder and Piaget (1958) explored the variables selected by students for this phenomenon and divided the variables that the student considers into three stages. In the first stage, students cannot even classify and generate a unifying principle. Therefore, they designate some objects as floaters because of their natural smallness, lightness, or flatness, for example, or because of their color. In the second stage, students confront contradictions and shift to a relative sense of weight. The object floats because it is "made of light things" or "light enough for

water". The third stage is characterized by a true evaluation of relative density. Meanwhile Piaget (2005) divided the selection of variables into four stages. In the first stage, which will be completed after around 5 years of age, floating is explained for animistic, moral reasons. In the second stage, extending on average from the age of 5 to 6, students think that boat is floating because it is heavy. On the contrary, a child in the third stage (on average aged 6-8) says that the boat is floating because it is light. Finally, a child in the fourth stage (about 9 years old) understands the relationship between the weight of the boat and the weight of the liquid component. Howe (2016) analyzed several studies and reclassified the variable stages into five levels. In level I, the child fails to use physical variables (personalism). A child of level II uses irrelevant physical variables like color, flatness, and temperature. In level III, the child begins to use relevant variables, such as lightness and largeness. A child of level IV is able to understand the relativistic use of relevant variables, such as lightness for its size, lightness compared to the water. In the final level, a child uses relative density. These studies have several implications because the levels or stages were divided based on the variables selected by students. However, the concept of buoyancy is missing in the highest level or in the stage mentioned above. This phenomenon can be explained using relative density, but the concept of buoyancy is essential in a complex context. To illustrate this phenomenon scientifically, we have to account for vector force, not scalar density (Kim, Kim, & Paik, 2017). In this regard, a systematic study is needed into the student's selection of variables including the use of forces (buoyancy and gravity).

Several studies have indicated the need to investigate the learning progression of the buoyancy concept, the focus of this study. By utilizing the framework of Physical Science curriculum from Foundational Approach to Science Teaching (FAST), Kennedy, Brown, Draney, & Wilson (2005) explored students' reasoning to justify their explanation of the concepts of sinking and floating and have developed the progression variables for those concepts (Stanford Education Assessment Laboratory, 2003). In the FAST unit on buoyancy, a middle school science curriculum presented the following concepts in order: mass, volume, mass and volume, density of object, density of medium, and relative density. In this study, "no response" level, "off target" level, "unconventional feature" level, and "productive misconception" level were represented as lower levels of "Mass."

Duschl, Schweingruber, & Shouse (2007)'s book, *Taking Science to School*, introduced learning progressions through the example, "developing an understanding of materials and measurement." That is, students in grades K-2 could make some distinctions between materials and object levels of description and use rich vocabulary for describing the properties of things, such as size, weight, texture, color, shape, taste, and smell. The students also had some initial ideas about which properties may appear at the object and the material levels. However, the young children had some limitations in acquiring the initial conceptual knowledge of materials, physical quantities such as weight and volume (Duschl, Schweingruber, & Shouse 2007; Krnel, Glazar, & Watson, 2003; Krnel, Watson, & Glazar, 1998), and essential characteristics of materials (e.g., density, boiling and melting points, solubility, thermal and electrical conductivity) (Duschl, Schweingruber, & Shouse, 2007; Johnson, 1996; Smith, Carey, & Wisner, 1985; Wilkening & Huber, 2002).

Although Piaget and Inhelder (1974) argued that elementary school students could develop an intuitive, abstract idea on the amount of matter in objects, many studies (e.g., Carey, 1991; Smith, Solomon, & Carey, 2005; Smith, Carey, and Wisner, 1985) have also provided evidence that students' conception of amount of matter is still incomplete relative to their conceptions of space and weight. However, Lehrer, Jaslow, & Curtis (2003) documented that third grade students could develop an understanding of weight and volume if provided with appropriate instruction. Lehrer, Schauble, Strom, & Pligge (2001) also found that the notion of density, a challenging notion even for much older children to grasp, became accessible to 5<sup>th</sup> graders with appropriate instruction. Duschl et al. (2007) and Lehrer and Schauble (2000) argued that to improve 3<sup>rd</sup> and 4<sup>th</sup> graders' understanding of the concepts of material properties, the instruction should distinguish weight from density and present the object weight as a joint form of its volume and density. Therefore, students in 3<sup>rd</sup>-5<sup>th</sup> grades should enhance their understanding of materials to develop a generalized conception of matter while recognizing weight and volume as key properties common to all materials and density as a distinguishing characteristic of material kinds (Duschl, Schweingruber, & Shouse 2007).

Among 6<sup>th</sup>-8<sup>th</sup> graders, an exceptional case was used to explain how the volume of matters could change based on the conditions in which mass or weight has been conserved. These are precisely the kinds of expectations

that students have been developing in grades 3–5, as they understand that matter takes up space and also has weight. Thus, educators should bear in mind that these ideas about material, matter, weight, volume, density, molecule, and atom exist within a broader array of ideas that are not only linearly related but also linked within a web of interconnected learning among multiple learning progressions (Duschl, Schweingruber, & Shouse 2007).

Hardy, Jonen, Moller, & Stern (2006) compared two different 3<sup>rd</sup> grade curricula on floating and sinking implemented within constructivist learning environments with varying teaching support. By examining the means of multiple choice tests, Schneider and Hardy (2013) determined that two main component processes of knowledge reconstructing students' knowledge about the concepts of floating and sinking are fragmentation and integration of the knowledge. Leuchter, Sbach, & Hardy (2014) expanded and implemented a one-year science learning program, complete with structured learning materials for preschool and elementary school students, to support conceptual change particularly in students' understanding of the concepts of floating and sinking and improving their scientific reasoning.

Alonzo (2012) distinguished between broad and narrow learning progressions. As an example of narrow learning progression, she suggested a specific idea such as sinking or floating for an elementary or a middle school age group. Yin, Tomita, & Shavelson (2014) examined the effect of a learning progression-aligned, formal embedded formative assessment on conceptual change and achievement in 6<sup>th</sup> graders. This study supported the idea that embedding formal formative assessments within a set of curricular activities established around an expected learning progression is a suitable way of promoting conceptual change alongside learning progression in science classrooms. However, we are skeptical of the learning progression of floating and sinking ideas shown in a narrow range of grade levels because these ideas are related to the buoyancy concept, which is related to many other scientific concepts covered in science curricula from elementary to high school years. We therefore determined that an investigation was warranted of the learning progression of floating and sinking ideas and buoyancy concept from elementary to high school.

To completely understand the fundamental reasons for sinking and floating, students are required to understand complex concepts that include a resolution of forces (i.e., buoyancy and gravity), water pressure, properties of matter, density, relative density, and other related concepts. These concepts, however, are not introduced sufficiently in elementary and middle school curricula (Yin, Tomita, & Shavelson, 2014). Rather, some curricula use the concept of relative density to explain sinking and floating (Pottenger & Young, 1992). Relative density is an especially challenging idea for students because density is a concept involving the ratio of mass to volume (Smith, Snir, J., & Grosslight, 1992), and relative density involves comparing two ratio variables (Yin, Tomita, & Shavelson, 2014). Heritage (2008) also suggested that buoyancy depends on the flat, air-filled hollow object, and on the density of the object in relation to the density of the medium (i.e., relative density). Highlighting the difficulties of the concept, Besson (2004) reported that the majority of upper secondary school students, first-year university students, and teachers-in-training in Belgium denied any relation between pressure forces and buoyant force regarding balloons in water or in air.

Despite its complexity in science, sinking and floating is such an exemplary phenomenon that almost all grade students develop personal theories to explain prior to entering the science classroom. However, no study has been conducted on learning progression framework based on the BEAR (Wilson, 2009), focusing on students' reasoning of matter, weight, volume, density, and the buoyancy phenomenon that occurs due to gravitational force. Therefore, in this study, we explore the learning progression of the buoyancy phenomenon in students from elementary to high school grades with respect to their levels of achievement. Loverude, Kautz, and Heron (2003) point out that university students still lack an understanding of buoyancy. In this study, the learning progression explored can be used to develop effective teaching activities or for curriculum development in order to improve understanding of the buoyancy concept. Therefore, this study can be helpful in systematically teaching buoyancy that not even college students understand.

## Research Goals

Our research goals were as follows:

- (1) To develop a construct map and assessment items of students' accounts of buoyancy based on theory and previous studies
- (2) To evaluate the validity and reliability of newly developed items on students' accounts of buoyancy
- (3) To empirically identify and describe the characteristics of different levels of understanding the buoyancy concept from elementary to high school students
- (4) To examine a construct map and learning progression models of the buoyancy concept

This learning progression can serve as a theoretical basis for designing, testing, and refining educational assessments as well as instructional tools and approaches that are responsive to the various ways of students' knowing and learning.

## STUDY CONTEXT

In the existing literature, the focus of the main studies related to buoyancy is students' conceptions; moreover, there are few studies on learning progression in Korea. Floating and sinking activities are introduced in preschool; Lee and Kim (2003) investigated the consistency of the classification criteria of floating or sinking objects among children between 4–6 years of age. They found that preschool children had various classification criteria, including properties of objects which were not related to the observed phenomena. They also found that children aged 4 focused primarily on the "size" of objects, while children aged 5–6 were more interested in their "weight." Cho and Lee (2011) divided six types of ideas about sinking and floating among children aged 4–5: personal and inconsistent conceptions, physical factors unrelated to the phenomena, mixed conception of related and unrelated physical factors, related physical factors, related physical factors and materials, and relative comparison of related physical factors. Kwon and Kwon (2000) studied the relationship between buoyancy conceptions and the cognitive levels of 6th graders. They developed items that investigated students' thoughts about floating and sinking phenomena. The variables of the items were the shape, size, weight, and materials of objects. One item, for example, asked which one floats or sinks between a ball shaped object and a boat shaped object of same weight and materials. Another item asked about the change in the weight of an object according to the depth to which it sank. Lee and Park (2012) discovered that only 17% of elementary school students understood the concept of buoyancy, while most of them held various alternative conceptions related to size of buoyance, the relationship to pressure, and the cause of buoyance. Learning that the factors affecting the degree of buoyancy include the volume of objects immersed in liquid and the density of the liquid enhanced the students' understanding. Lee (2000) discovered that not only students but also elementary school teachers had difficulties in understanding the relation between pressure and density of liquid and between buoyance and water weight pushed out by volume of an object. The students' responses depended on the types and situations of items related to the same concepts. In addition, Ku (2002) suggested that many elementary school teachers did not have a complete grasp of the scientific conceptions related to weights of objects in water. He insisted on the need to reform teacher education as the teachers' various, alternative conceptions could affect students' understanding.

To explain the phenomena of sinking and floating, the concept of force is introduced in middle school curriculum. Lee (2009) surveyed middle school students' conceptual understanding of gravity and buoyancy and learned that they had alternative conceptions of force acting on different sized wooden blocks and factors affecting the degree of buoyance. Kim and Kim (2012) also investigated middle school students' thoughts about buoyancy and found that they used the concepts of force, pressure, and water pressure to explain the phenomena of floating and sinking. The students believed that buoyance depends on weights, the depth to which an object sinks, and the shapes of objects. These misconceptions were observed continuously from elementary to middle school students. Seo (2004) investigated high school students' understanding of water pressure and buoyance and discovered serious inconsistencies in the students' responses. The level of students' understanding of the concept of buoyancy was lower than their understanding of water pressure, and they also had various other misconceptions. The

**Table 1.** Participants' information (year, gender, and grade)

| School     | Grade | Male |       | Female |       | Total |        |
|------------|-------|------|-------|--------|-------|-------|--------|
|            |       | N    | %     | N      | %     | N     | %      |
| Elementary | 3     | 36   | 3.54  | 34     | 3.34  | 70    | 6.88   |
|            | 4     | 50   | 4.92  | 59     | 5.80  | 109   | 10.72  |
|            | 5     | 72   | 7.08  | 75     | 7.37  | 147   | 14.45  |
|            | 6     | 72   | 7.08  | 66     | 6.49  | 138   | 13.57  |
| Middle     | 7     | 57   | 5.60  | 49     | 4.82  | 106   | 10.42  |
|            | 8     | 67   | 6.59  | 60     | 5.90  | 127   | 12.49  |
|            | 9     | 43   | 4.23  | 52     | 5.11  | 95    | 9.34   |
| High       | 10    | 55   | 5.41  | 80     | 7.87  | 135   | 13.27  |
|            | 11    | 37   | 3.64  | 25     | 2.46  | 62    | 6.10   |
|            | 12    | 16   | 1.57  | 12     | 1.18  | 28    | 2.75   |
| Total      |       | 505  | 49.66 | 512    | 50.34 | 1017  | 100.00 |

questions used in these studies were adapted to develop the questionnaire used in the present study to investigate Korean students' learning progression.

## METHODOLOGY

### Research Design

In this paper, our goal is to develop and validate a learning progression and assessment for teaching the concept of buoyancy. The development of the learning progression is an iterative process, as is typical of design-based research. Design-based research is used to develop design artifacts using iterative cycles of implementation and evaluation (Collins, 1992; Kelly, 2004). Design-based research in education has typically focused on the development of instructional strategies, principles, or models as design artifacts (e.g., Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). In contrast, our work focused on developing design artifacts in the form of connected assessments and a learning progression framework. We developed an initial hypothetical framework, defining upper and lower anchors and developing assessments based on that framework, before using the results of the assessments to revise the framework, which led to the creation of new assessments. To evaluate the construct validity of the items measuring students' understanding of the buoyancy concept, we used the Messickian (1995) approach.

### Participants

Students in grades 3–12 participated in this study ( $N = 1,017$ ). We sampled several regions in Korea using the convenience sampling method. In order to minimize the threat of convenience sampling and to generalize the interpretation of results, students were sampled from as many schools as possible across various regions of Korea. As a result, schools in seven regions of Korea were sampled and these regions are relatively spread out geographically. We thus tried to minimize the threat of generalization according to the characteristics of students in different regions (Shadish, Cook, & Campbell, 2002). The descriptions of the participants are displayed in [Table 1](#).

Given the cross-sectional nature of the present study, the homogeneity of academic ability among each group (e.g., elementary, middle, and high school students) should be considered. In Korea, middle school students can choose among three high school tracks: humanities, vocational, and art. To determine whether high achieving students tend to choose the humanities track over others and whether the distribution of students' achievement in

middle and high schools is different, we verified the appropriate government reports. We did not find any significant differences in the distribution of students' achievement in middle and high school and concluded that middle and high school students are homogeneous in terms of academic abilities.

**Statistical analyses.** Here, we used a variety of statistical methods to evaluate the item quality (i.e., construct validity and reliability) and students' learning progression. First, we used Rasch analysis (a two-dimensional partial credit model) to evaluate item dimensionality, item fit (Mean Square), person and item measures (person ability and item difficulty), and Rasch reliability (Item separation and EAP/PV reliability). ConQuest version 4.5.0 was used for the Rasch analysis. Second, both exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) were conducted to evaluate the structure of the test items. Cronbach's alphas were calculated to evaluate the level of internal consistency. Finally, Multivariate Analysis of Variance (MANOVA) was used to examine the students' learning progression through academic years. The CFA was performed using AMOS version 22; all other statistical analyses were conducted with SPSS version 22.

## FINDINGS

Development of a construct map and assessment items of students' accounts of buoyancy

### **Hypotheses of the Progression Related to Buoyancy Concept**

Varelas's (1996) conceptual framework was developed in a unit on sinking and floating, designed to engage students in the deductive reasoning of scientific activity in a 7th grade science class. Varelas suggested five criteria: (1) directionality of the link between the density of a material and its behavior in water, (2) specificity of the link between the density of a material and its behavior in water, (3) reference to two forces acting on a material submerged in water, (4) linking the relative strength of the two forces with the density of the submerged object and the object's behavior in water, and (5) explaining the link between the relative strength of the two forces and the density of the submerged object.

Raghavan, Sartoris, Glaser (1998) studied children's ideas about floating and sinking and suggested the Model-Assisted Reasoning in Science (MARS) project; they created a model-centered, computer-supported 6<sup>th</sup> grade science curriculum. In the MARS instruction, the units are constructed in order of the properties of objects (e.g., area, volume, mass), force concepts (e.g., force, net force, weight), and applications (e.g., forces in fluids, buoyant force, floating and sinking) to help strengthen students' understanding. In addition, MARS represented five levels of learning progression. Students in level 1 could not distinguish between mass and volume. Level 2 students believed that the degree of buoyancy was affected by the kind of liquid and the volume of the object. Level 3 students did not believe that the cylinders of equal masses have different sizes and believed that the buoyant forces exerted on the two cylinders would be different because buoyant force depends on size, not mass. Level 4 students believed that buoyant force does not depend on mass, but on depth and volume. Unlike their level 3 peers, students in level 4 could make a partial connection and explain that buoyant force depends on volume. Level 5 students were able to state that buoyant force does not change because of weight or mass, but depends on volume of the object and the density of the liquid.

The FAST Physical Science curriculum (Stanford Education Assessment Laboratory, 2003) presented learning progression in the following order: mass, volume, mass and volume, density of object, density of medium, and relative density on buoyancy. Kennedy, Brown, Draney, & Wilson (2005) study added "no response," "off target," "unconventional feature," and "productive misconception" levels as lower levels of mastering the "mass" concept. Yin, Tomita, & Shavelson, (2014) study identified level 1 (mass or volume), level 2 (mass & volume), level 3 (object density), and level 4 (relative density). Siegel, Esterly, Callanan, Wright, & Navarro (2007) suggested 4 levels of parents' explanations related to sink-or-float task: (1) no information, (2) other property explanation (e.g., texture, shape, function/identity), (3) density-relevant explanations (e.g., material kinds, weight, size, insides, relates to water), and (4) density explanation.

Leuchter, Sbach, & Hardy (2014) suggested that misconceptions commonly involve a one-dimensional focus on salient features such as objects' weight, size, or shape. Student explanations are bound in physical

experiences about the properties of the object. Although they frequently refer to weight, it is likely to be conceptualized as a property of the object, rather than a force (Parker & Heywood, 2013). While 3<sup>rd</sup> graders are unlikely to generate scientific explanations of buoyancy force and density without instruction (Hardy, Jonen, Moller, & Stern, 2006), Yin, Tomita, & Shavelson (2008) revealed a variety of students' misconceptions related to sinking and floating, such as size and heaviness and objects with holes. It should be noted that students' ideas about sinking and floating in Yin et al.'s (2008) study also seems to be at a lower level than their understanding of mass. We hypothesized that formative assessments aligned with these expected learning progressions might be an effective way to promote students' conceptual change about sinking and floating.

### Specifying Construct Stage

Learning progressions are delineated by an upper and a lower anchor (Gunckel, Covitt, Salinas, & Anderson, 2012). Students' tentative understanding of a particular idea or concept upon entering the learning progression defines the lower anchor (Neumann, Viering, Boone, & Fischer, 2013). The students at the lowest level in a learning progression framework rely primarily on intellectual resources from outside of school, including their personal experiences and native languages (Jin & Anderson, 2012). The upper anchor is the level of understanding expected from students once they have mastered the learning progression (Neumann et al., 2013).

Level 4 in the learning progression framework involves descriptions of accounts that use buoyancy as a scientific concept. The intermediate steps of levels 2 and 3 serve as stepping stones that let students connect between the starting and ending points and are achieved through effective instructional intervention. Thus, it is important to identify and describe the characteristics of the middle levels of learning progressions. Based on the previous studies related to buoyancy, we propose the construct map shown in [Table 2](#).

We developed open-ended, short essay type questions to evaluate students' learning progression of the buoyancy concept based on the literature review and the previously developed instruments (see supplementary materials for items). First, we analyzed the presence/absence of particular concepts in students' responses using an analytic rubric. Then, we determined the level of each response based on the four different learning progression levels of the buoyancy concept (see [Table 2](#)).

### Item Development Process

Based on the construct map developed through literature review of the concept of buoyancy and learning progression, we developed 16 open-ended (written) assessments spanning two contexts: characters of objects and relationship between objects and water. The content validity of these 16 items was evaluated by 10 physics and chemistry education experts. Meanwhile, the items were pilot tested with approximately 100 students to determine the most difficult questions. This item was removed because it is difficult to trace the student's learning progression, as very difficult questions are rarely asked by students of any scientific background, regardless of grade. In addition, we interviewed 10 middle and 10 high school students to explore students' reasoning processes when they were solving the questions (i.e., substantive validity). Based on the collected data, we removed three items and finalized 13 items as the test for the buoyancy concept.

In this study, we used two different contexts: the characters of objects and the relationship between objects and water. The difference between these two contexts is that the second context requires students to exercise their proportional reasoning skill, while the first one does not. Given that the buoyancy phenomenon occurs because of the relative difference in the densities of two different objects, the test items of the second context can reveal students' understanding of the buoyancy concept more effectively. The test items, however, are generally more difficult because they require students to exercise their proportional reasoning skills.

**Table 2.** Construct map for 4 stepped learning progression for buoyancy

| Level  | Classification                 | Coding                    | Example of students' responses  |  |
|--------|--------------------------------|---------------------------|---|--|
| 0      | No response                    | No response               | No response   |  |
| 1      | Concept Of Situational Context | Material of object        | - The small wooden beads will be on top because wood floats on water.<br>- The small wooden beads are made of wood, and the small metal beads are made of iron. So, the small wooden beads are likely to float, and the metal beads are likely to sink.   |  |
|        |                                | Shape of object           | - Because the flat bottom of the boat-shaped object has even contact with the water, but the ball-shaped object does not have even contact with water.<br>- Because the ball-shaped object does not float in water more easily than the boat-shaped object.   |  |
|        |                                | The present of air        | - It floats in water like a tube full of air.<br>- An inflated balloon has air, and air never sinks in water.<br>- Because air cannot enter a foil crumpled up into a ball.<br>- The boat-shaped object floats because it has air, but the ball-shaped object does not.   |  |
|        |                                | Amount of water           | - Because the weight increases if there is more water.<br>- It floats well because there is lots of water.  |  |
|        | An incomplete basic concepts   | Weight                    | - Light objects float, and heavy objects sink.  |  |
|        |                                | Volume                    | - All small objects float.<br>- If the inside is empty, the volume increases, and so, it floats.  |  |
|        | 2                              | An complete basic concept | Weight  | - The metal objects are likely to sink because they are heavier than wooden objects.   |
|        |                                |                           | The surface area of an object   | - An inflated balloon floats because the area of the object in contact with the water is larger than the area of an uninflated balloon.<br>- The boat-shaped object has wide area of contact with the water, but the ballshaped object does not. |
| Volume |                                |                           | - The boat-shaped object floats on water because of its large volume, but it sinks when it is crumpled into a ball because it becomes smaller in size.  |  |
| 3      | An incomplete science concept  | Density                   | - The same material objects have the same density, so they can float on the water.<br>- One object floats and the other object also floats because they have the same density.<br>- The metal beads are heavy for its size.<br>- It is heavy, and small in size. Large density makes it sink.   |  |
|        |                                | Buoyancy                  | - The wooden beads have a strong buoyancy force, but the metal beads have a weak buoyancy force. So, the wooden beads float well on the water, and the metal beads do not float.<br>- The air in the glass makes buoyancy.<br>- The empty space plays a role in buoyancy.<br>- The boat-shaped objects float well by buoyancy, but the ball-shaped object is not affected by buoyancy.  |  |
|        |                                | Density difference        | - The boat-shaped object is light for its size when floating on the water. That means that law of density is at work. But it will sink when it is crumpled into a ball because it will have a higher density.<br>- The density of wooden beads is lesser than water, and the density of metal beads is higher than water. So, the wooden beads float on the water, but the metal beads sink.  |  |
|        |                                | Buoyancy                  | - A metal bead sinks in water because the downward gravitational force acting on it is greater than the upward buoyant force.<br>- A wooden bead floats (partially immersed in water) because the downward gravitational force acting on it is equal to the buoyant force.<br>- The size of buoyancy depends only on the volume of the submerged object and does not depend on the shape of the object, the amount of water, or the depth in water. Therefore, the scale, which was horizontal in the air, moves only when the volume of both objects is different. It is thus tilted to the opposite side of larger volume object because the larger volume object receives larger buoyancy. |  |
| 4      | A complete science concept     | water pressure difference | - If two objects have the same weight, the object with a larger surface is more pressured by water.   |  |

**Table 3.** Two dimensional partial credit Rasch model fit indices

|             |        | Estimate | Error | Unweighted<br>MNSQ | T     | Weighted<br>MNSQ | T     |
|-------------|--------|----------|-------|--------------------|-------|------------------|-------|
| Dimension 1 | Item1  | -0.166   | 0.057 | 0.95               | -1.10 | 0.95             | -1.00 |
|             | Item2  | -0.402   | 0.058 | 0.95               | -1.20 | 0.95             | -1.20 |
|             | Item3  | -0.350   | 0.059 | 0.87               | -3.00 | 0.87             | -3.10 |
|             | Item4  | 0.409    | 0.069 | 1.08               | 1.70  | 1.06             | 1.30  |
|             | Item5  | 0.253    | 0.059 | 1.09               | 2.00  | 1.06             | 1.00  |
|             | Item6  | 0.257    | 0.071 | 0.98               | -0.50 | 0.99             | -0.20 |
| Dimension 2 | Item7  | -0.568   | 0.062 | 1.04               | 0.90  | 0.96             | -0.80 |
|             | Item8  | 0.250    | 0.081 | 0.92               | -1.70 | 1.00             | 0.00  |
|             | Item9  | -0.086   | 0.073 | 0.96               | -0.90 | 0.95             | -1.00 |
|             | Item10 | 0.033    | 0.074 | 0.85               | -3.40 | 0.86             | -2.70 |
|             | Item11 | 0.322    | 0.114 | 0.92               | -1.80 | 0.90             | -2.40 |
|             | Item12 | -0.149   | 0.067 | 1.07               | 1.50  | 1.08             | 1.50  |
|             | Item13 | 0.198    | 0.077 | 1.23               | 4.80  | 1.18             | 3.10  |

### Validity and Reliability of the Developed Items on Students' Accounts of Buoyancy

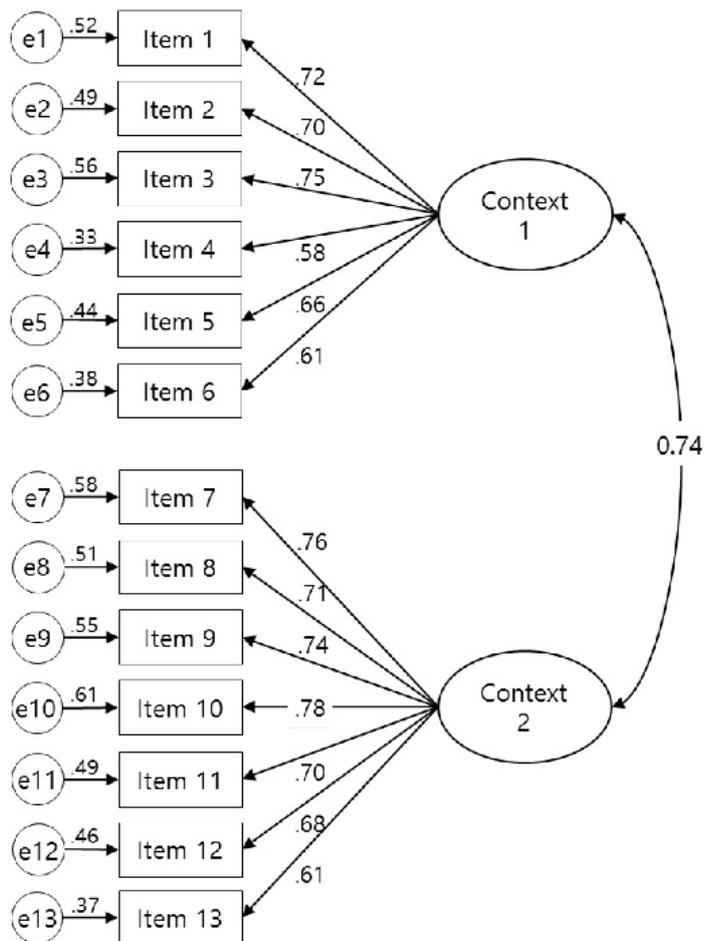
To evaluate the construct validity of items measuring students' understanding of the buoyancy concept, we used the Messickian (1995) approach. Messick (1995) identifies six aspects of construct validity: (1) the intended content coverage by experts (2) the reasoning processes (i.e., substantive validity) (3) structure of test items, (4) alignment of the assessment scores with scores of similar assessments attempting to measure the same or similar constructs, (5) the generalizability of scores, and (6) the consequences of using scores. We checked for content validity and substantive validity when we developed the test items. Here, we report the item fit indicated by the Rasch analysis, internal consistency of reliability, and evidence of structure of the test items. **Table 3** shows that the unweighted mean square and weighted mean square of the test items meet the benchmark of standard tests (see Wright & Linacre, 1994); since we used the partial credit model, MNSQ values between 0.6 and 1.4 were determined to be acceptable. We found four cases of T values outside of  $-2$  to  $2$  range; however, given the large sample (over 1,000) and the acceptable MNSQ values, the T values have relatively little bearing (Boone et al., 2014). In addition, the internal consistency of test items was acceptable. The Cronbach's alpha for items 1-6 (first dimension) was 0.823; the Cronbach's alpha of items 7-13 (second dimension) was 0.877; and the Cronbach's alpha of all 13 items was 0.903.

As mentioned above, we developed the 13 items based on two contexts and tested the structure of the test items to fit two dimensions. First, we computed the deviance and Akaike Information Criterion for one-dimensional model and two-dimensional model. Our results illustrated that the two-dimensional model (deviance = 22829, AIC = 22913) is a better fit than the one-dimensional model (deviance = 23153, AIC = 23233). In addition, we conducted exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). The results of the EFA using principal components analysis with our 13 items were fit to a 2-factor model (**Table 4**). In addition, we conducted CFA using structural equation modeling. We input our data to the hypothetical model shown in **Figure 1** and found acceptable fit indices (Chi-square = 341.55,  $df = 64$ ,  $p = 0.000$ , root mean square residual (RMR) = 0.033, goodness-of-fit index (GFI) = 0.933, adjusted goodness-of-fit index (AGFI) = 0.904, normed-fit index (NFI) = 0.924, incremental fit index (IFI) = 0.938, Tucker-Lewis index (TLI) = 0.924, comparative fit index (CFI) = 0.937, root mean square error of approximation (RMSEA) = 0.074 [90% CI 0.067-0.082]). Based on Hooper, Coughlan, & Mullen (2008) intensive review on the benchmark of fit indices of structural equation modeling, our model met the benchmark (e.g., RMSEA < 0.08, GFI, AGFI, NFI, IFI, TLI, CFI > 0.9).

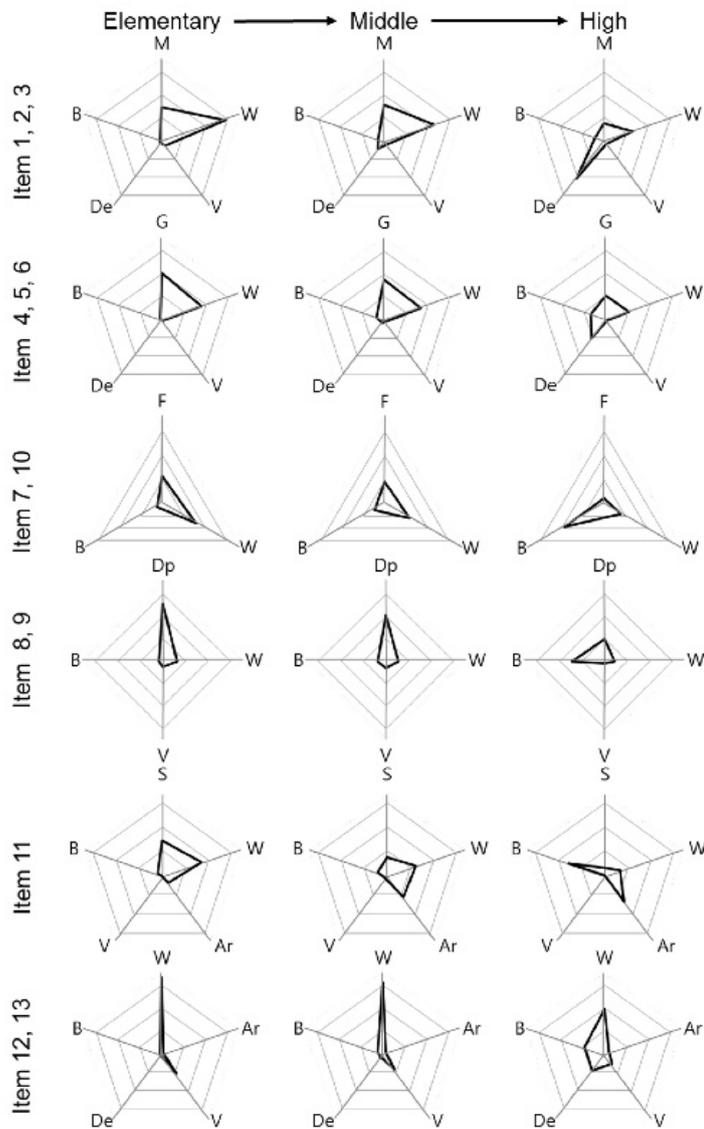
The item separation reliability of Rasch analysis was 0.950; the EAP/PV reliability of the first dimension was 0.786, while that of the second dimension was 0.816.

**Table 4.** Exploratory factor analysis of 13 items

|         | <b>Factor 1</b> | <b>Factor 2</b> |
|---------|-----------------|-----------------|
| Item 3  | <b>0.818</b>    | 0.159           |
| Item 1  | <b>0.748</b>    | 0.220           |
| Item 2  | <b>0.746</b>    | 0.203           |
| Item 5  | <b>0.625</b>    | 0.349           |
| Item 4  | <b>0.604</b>    | 0.245           |
| Item 6  | <b>0.542</b>    | 0.379           |
| Item 9  | 0.174           | <b>0.791</b>    |
| Item 10 | 0.271           | <b>0.773</b>    |
| Item 8  | 0.207           | <b>0.747</b>    |
| Item 11 | 0.201           | <b>0.741</b>    |
| Item 7  | 0.323           | <b>0.721</b>    |
| Item 12 | 0.452           | <b>0.571</b>    |
| Item 13 | 0.333           | <b>0.564</b>    |



**Figure 1.** Confirmatory factor analysis of 13 items using structural equation modelling, Sample size 788, Chisquare = 341.55, df = 64, p = .000, RMR = .033, GFI = .933, AGFI = .904, NFI = .924, IFI = .938, TLI = .924, CFI = .937, RMSEA = .074 (90% confidence interval: 0.067 - 0.082)



**Figure 2.** Radar chart showing the change of key conceptual elements of buoyancy concept from elementary to high school students (M: material, G: gas, Dp: deep, F: fluid, Am: amount of water, S: shape, W: weight, Ar: area, V: volume, De: density, B: buoyancy)

### Cross-Sectional Change of Understanding of Buoyancy Concept

**Radar chart of key conceptual elements of buoyancy concept.** We used a radar chart to illustrate how the key conceptual elements of the buoyancy concept changed through the academic years. We can see the difference in the conceptual structure by comparing the shape of the black line within the radar chart (Figure 2). We used the average scores of items measuring the same conceptual elements. For example, students' answers in items 1, 2, and 3 include material (M), weight (W), volume (V), density (De), and buoyancy (B). Overall, the frequencies of conceptual elements in elementary and middle students' responses were similar, while that of high school students' responses was quite different. In this radar chart, we found that the learning progressed more rapidly in high school.

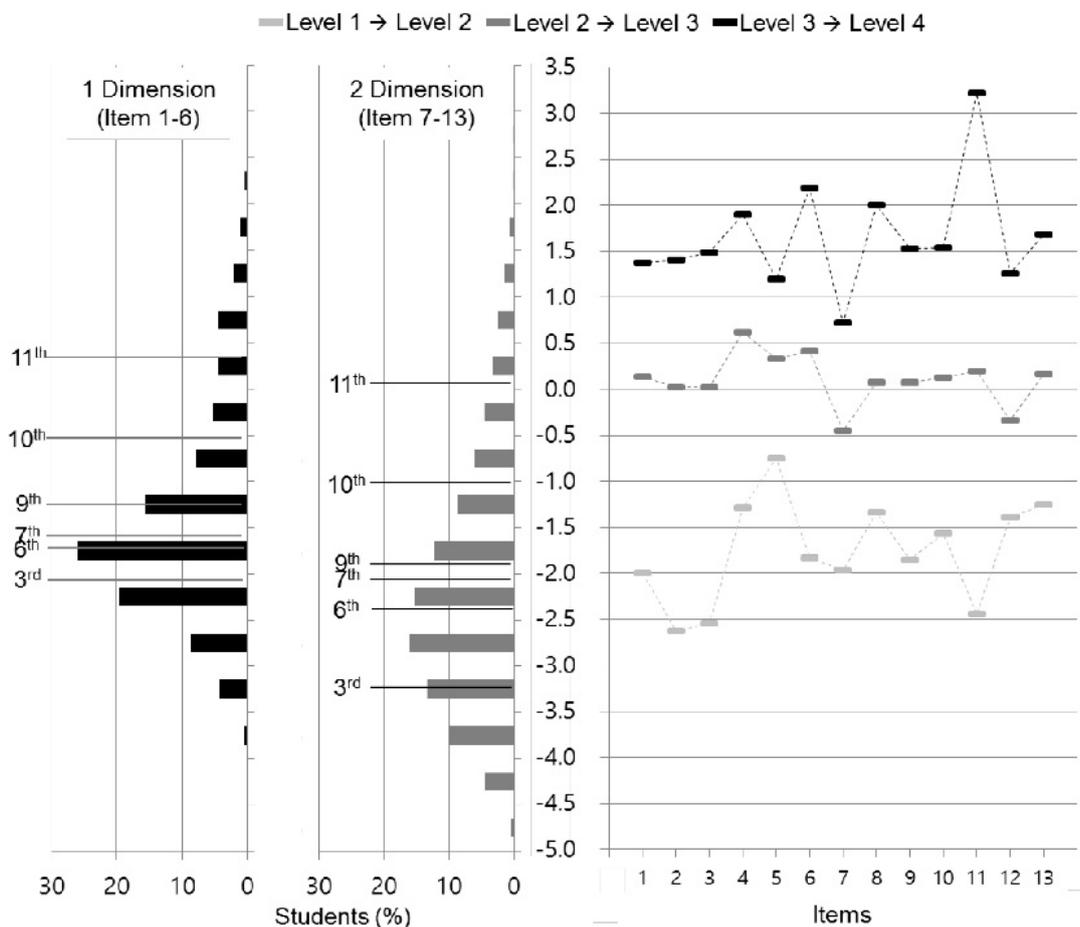
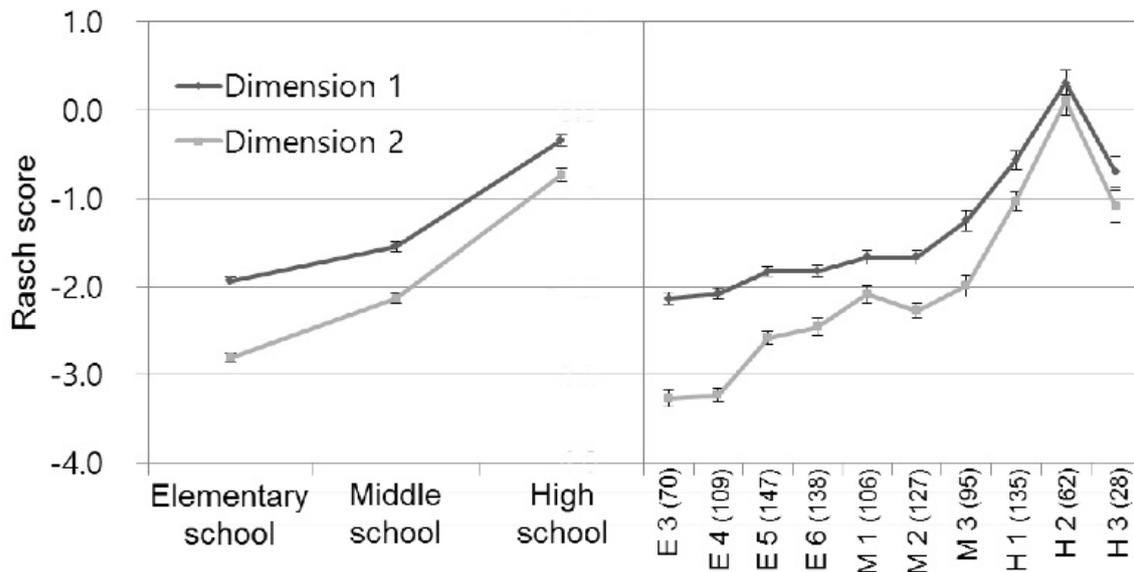


Figure 3. Wright map for two-dimensional partial credit Rasch model

### Learning Progression of Students' Buoyancy Concept

We investigated the students' progression in understanding the buoyancy concept using the Wright Map from Rasch analysis. This Wright Map illustrates how our four-step hypothetical learning progression model fits a hierarchy of learning progression levels. Figure 3 shows the Wright Map displaying individual abilities (left bar chart) and item difficulties (right panel; see Bond & Fox, 2007). Wright Map is an effective method to determine the item difficulty against individual abilities. A student with low ability (e.g., 3<sup>rd</sup> year student) and a relatively easy item (e.g., level 1) are placed at the bottom of the map. Higher ability students (11<sup>th</sup> year student) and more difficult items (level 4) are placed near the top of the map. If a student's ability is equal to the difficulty of a particular item, both student and item are placed at the same height.

In the right panel, the light gray hyphen (lowest) indicates the threshold level from level 1 to level 2. Likewise, dark gray hyphen (middle) indicates the threshold level from level 2 to level 3, and a black hyphen (highest) indicated the threshold level from 3 to 4. Thus, the area between the light gray and dark gray hypens indicates students who are in level 2. The lowest logit scale of threshold level 1 to 2 is Item 2 (-2.63) and Item 3 (-2.55), while the highest logit scale for this is Item 13 (-1.26) and Item 5 (-0.76). The lowest logit scale of threshold level 2 to 3 is Item 7 (-0.45) and Item 12 (-0.33), while the highest logit scale for this is Item 6 (0.41) and Item 4 (0.62). Finally, the lowest logit scale of threshold level 3 to 4 is Item 7 (0.72) and Item 5 (1.20); the highest logit scale for this is Item 6 (2.19) and Item 11 (3.21). The gaps between the thresholds across items were different.



**Figure 4.** Cross-sectional change of Rasch person measures across academic years

The left panel shows the distribution of students' abilities. Overall, students performed better in Dimension 1 than in Dimension 2. In Dimension 1, the largest number of students (26.06%) was in the logit scale  $-2$  to  $-1.5$ , which indicated levels 1 and 2. The second largest number of students (19.57%) was in the logit  $-2.5$  to  $-2$ ; the third largest number of students (15.54%) was in the logit  $-1.5$  to  $-1$ . In Dimension 2, the largest number of students (16.03%) was in the logit scale  $-3$  to  $-2.5$ , which indicated below level 1. The second largest number of students (15.24%) was in logit  $-2.5$  to  $-2$ , and the third largest number of students (13.37%) was in the logit  $-3.5$  to  $-3.0$ .

The Wright Map illustrated how the items were effectively distributed to measure student abilities. A notable feature of our Wright Map is that most elementary and middle students are placed around the threshold for level 1 to 2 (light gray hyphen). The highest ability students did not reach the threshold for level 4. Most students were below the threshold between level 3 and 4. These findings matched our expectations as we designed our instrument to be more difficult than average to avoid ceiling effects and examine students' future progression. Another notable feature of our Wright Map is that the kurtosis of student ability distribution in Dimension 1 is more pronounced than that in Dimension 2. This pattern indicates that Dimension 2 items performed better in differentiating students.

**Figure 4** illustrates the students' progression in the buoyancy concept through academic years from the 3<sup>rd</sup> (3<sup>rd</sup> year in elementary school) to 12<sup>th</sup> grade (3<sup>rd</sup> year in high school). In Dimension 1, the averages of students' ability (logit scale) by grade were as follows: G3 ( $-2.13$ ), G4 ( $-2.08$ ), G5 ( $-1.83$ ), G6 ( $-1.82$ ), G7 ( $-1.67$ ), G8 ( $-1.67$ ), G9 ( $-1.25$ ), G10 ( $-0.57$ ), G11 ( $0.31$ ), and G12 ( $-0.70$ ) (G3, G4, G5... = 3<sup>rd</sup> grade, 4<sup>th</sup> grade, 5<sup>th</sup> grade...). The averages of thresholds from level 1 to 2, level 2 to 3, and level 3 to 4 in Dimension 1 were  $-1.84$ ,  $0.26$ , and  $1.59$ , respectively. Notably, G3 and G4 were below level 1, G5–G10 and G12 were between levels 1 and 2, and only G11 was over level 3. In Dimension 2, the averages of students' ability were as follows: G3 ( $-3.26$ ), G4 ( $-3.23$ ), G5 ( $-2.58$ ), G6 ( $-2.46$ ), G7 ( $-2.09$ ), G8 ( $-2.28$ ), G9 ( $-1.99$ ), G10 ( $-1.04$ ), G11 ( $0.11$ ) and G12 ( $-1.09$ ). The averages of thresholds from level 1 to 2, level 2 to 3, and level 3 to 4 in Dimension 2 were  $-1.69$ ,  $-0.02$ , and  $1.71$ , respectively. Likewise, it was noted that G3–G9 were under level 1, G10 and G12 were between level 1 and 2, and only G11 was over level 3. The pattern indicated by **Figure 4** is that the gap between students' ability between Dimension 1 and 2 decreased through the academic years and that the highest grade students (G12) showed lower performance than G11.

We conducted a MANOVA to examine the differences between students' abilities across school levels. The overall school effect of MANOVA (Wilks' Lambda) was significant ( $F[4,2026] = 129.906, p = 0.000$ , partial eta-squared [PES] = 0.204). The average abilities of Dimension 1 were  $-1.933$  (Standard deviation [SD] = 0.707) for elementary,  $-1.546$  (SD = 0.945) for middle, and  $-0.341$  (SD = 1.212) for high school students. The average abilities of Dimension 2 were  $-2.801$  (SD = 0.985) for elementary,  $-2.134$  (SD = 1.073) for middle, and  $-0.728$  (SD = 1.311) for high school students. The univariate analysis also revealed significant differences in students' abilities across school levels (Dimension 1:  $F[2,1014] = 230.706, p = 0.000$ , PES = 0.313; and Dimension 2:  $F[2,1014] = 272.584, p = 0.000$ , PES = 0.350). Furthermore, pairwise comparisons using the Bonferroni correction revealed that the significances of differences between all combinations of the school levels (e.g., elementary vs. middle) were less than 0.001, indicating that students gradually advanced their learning progression of buoyancy concept through school levels. However, it must be noted that even high school students did not reach level 4. The gap between students' abilities of Dimension 1 and 2 was significantly decreased across school levels. The averages of the gap (Dimension 1 measure-Dimension 2 measure) were 0.869 (SD = 0.652) for elementary, 0.588 (SD = 0.672) for middle, and 0.387 (SD = 0.765) for high school ( $F[2,1014] = 41.025, p = 0.000$ , PES = 0.075). Pairwise comparisons using the Bonferroni correction also revealed that the significances of differences in gaps between all combinations of the school levels were less than 0.01.

## DISCUSSION

The purpose of this study was to identify students' learning progression for the buoyancy concept. To this end, we developed a new, open-ended instrument, which included 13 items of two different contexts of buoyancy. We collected more than 1,000 elementary, middle, and high school students' responses (>13,000 responses) and scored them based on the partial credit model (1-4 level). In this section, first, we discuss the quality and the functioning of the new instrument and then the characteristics of students' learning progression in the buoyancy concept.

### Quality of a New Instrument

Our analyses comprising internal consistency (Cronbach alpha), CFA using equation modeling, and Rasch analysis for item fit and person/item reliability revealed that the instrument met the benchmark of a quality instrument. In addition to our rigorous statistical analyses, we verified the content validity with chemistry and physics experts and more than 10 experienced science teachers. Moreover, our in-depth clinical interviews with the sample revealed that the students' ways of solving the test items matched our expectations: the sample did not reach level 4. Even high school students only managed to reach the thresholds of level 2 to 3. We set up level 4 as a learning goal of buoyancy concept, which is a normative scientific concept.

### Differential Learning Progression of Buoyancy Concept in Different Contexts

We designed our test items based on two different contexts of buoyancy. One is the context of floating of various objects (Dimension 1) and the other is the mutual relationship between two objects in water (Dimension 2). The notable difference between the two contexts is that the second context requires students to engage their proportional reasoning skill. The buoyancy phenomenon occurs because of the relative difference of the densities of two different objects. Thus, the test items in the second context can more effectively reveal students' understanding of the buoyancy concept; however, the test items are more difficult given that they require students to exercise their proportional reasoning skills.

Statistical analyses revealed that students' abilities in the two different contexts were differentiated. In addition, our results revealed that items in Dimension 1 were more difficult than those in Dimension 2. Another notable feature is that the difficulty gap between two dimensions decreased through the academic years. That is, the higher ability students were less influenced by the different contexts of the test items.

Our results provide evidence on the contextual effect of assessment items. Previous studies on the assessments of evolution (Nehm & Ha, 2011; Nehm, Nehm, Opfer, & Ha, 2012, Opfer, 2012) and photosynthesis

(Weston, Haudek, Prevost, Urban-Lurain, & Merrill, 2015) revealed that the success of students' problem solving is influenced by the contexts of items. In general, novices (i.e., our sample) do not identify the core concepts of the assessment (e.g., natural selection idea in evolution assessment) and tend to focus on surface features of the items (e.g., type of taxa evolving) when they solve the problem (Baxter & Glaser, 1998; Chi, Feltovich, & Glaser, 1981). Bransford, Brown, & Cocking (1999) and Opfer, Nehm, & Ha (2012) noted that one of characteristics of expertise in problem solving is that knowledge becomes more abstract and less specific to the specific contexts. Thus, experts are able to transfer their knowledge to different contexts more easily than novices. Our result showing the decrease of the difficulty gap between two different dimensions across grades may be evidencing the effect of expertise in problem solving on contextual effects. In addition, our dual-context assessment of buoyancy can be used to measure the contextual effects of students' problem solving.

### **Recommendations for Teaching the Buoyancy Concept**

Our results demonstrated that the learning progression was slower between elementary to middle schools but relatively faster between middle to high schools. We used the Raghavan, Sartoris, & Glaser (1998) concepts to explain this finding. Raghavan et al. (1998) illustrated that students in the lowest level (level 1) could not understand the difference between mass and volume. In addition, students in the level 2 tend to believe that the kind of liquid (e.g., oil vs. water) is important to buoyant force. Young students first need to understand the basic properties of objects such as materials, the presence of gas, and shape. In addition, they need to understand that such concepts are not only applied in particular contexts but also to all natural phenomena.

In addition, students need to understand the concept of proportion, and it is a prerequisite to understanding the concepts of density, relative density between two materials, and water pressure. Density, meaning mass per unit volume, and water pressure, meaning the force applied by water to the surface of an object per unit area, are both ideas related to proportion. Therefore, developing an understanding of proportion may be the scaffolding required to understand the buoyancy concept.

However, much research into the concept of buoyancy focuses on the effects of teaching strategies, rather than on students' development of the buoyancy concept. Many studies have thus reported on the effectiveness of teaching strategy rather than students' qualitative change in relation to the buoyancy concept. Several studies have considered the effectiveness of teaching the buoyancy concept, but one element reported in these studies is a score change obtained as a result of simple multiple choice questions (Gang, 1995; Heron, Loverude, 2009; Loverude, Shaffer, & McDermott, 2003; Kariotogloy, Koumaras, & Psillos, 1993; She, 2005; Unal, 2008). The aim of science education is not simple problem solving, but acquiring a deep understanding of scientific principles (Duschl, Schweingruber, & Shouse, 2007). The change affecting the students shown in the previous research is not only done in a simple judgment (true or false), but there is also no judgment of the level of the students examining the phenomenon. Although some studies have derived this data qualitatively, qualitative analysis has limitations in describing students' changing understanding of the buoyancy concept (Hsin, & Wu, 2011; Radovanović, & Slisko, 2013; Çepni, & Şahin, 2012). However, this paper shows the path to acquiring knowledge of the concept of buoyancy, so it can provide valuable information when designing teaching strategies for buoyancy concept. In addition, it can help to systematically demonstrate the qualitative changes affecting students.

### **Limitation**

We have made progress toward defining a conceptually coherent and empirically validated learning progression that describes how students construct and use accounts of the buoyancy concept. However, it is necessary to point out some limitations of this study. First, we sampled several regions in Korea, and we used the convenience sampling method. In addition, the sample was limited to the region of Korea. Thus, it can be a threat to external validity. Second, because Korea's national level curriculum usually changes approximately every five years, there are some differences in the curriculum provided by school level; thus, the curriculum provided to the sampled students differed. Therefore, attention should be paid when interpreting the results.

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