Chapter 1
Introduction to the Study

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Chapter 1

Introduction to the Study

1.1 Introduction
The primary aim of this research is to investigate whether exploration in a computer-based learning environment could help foster a more in-depth as well as extensive but yet more precise level of qualitative understanding of buoyancy. It is a knowledge-rich domain which is very much a part of our daily lives but is often poorly understood. The discussion of this chapter is organised into five main headings: buoyancy domain, computer-based learning environments, qualitative understanding, aims of the research, and outline of the thesis.

1.2 Buoyancy Domain
The issues raised here pertain to aspects of buoyancy that are emphasised in a formal classroom instruction and the knowledge gaps in physical laboratory buoyancy-related experience. Also, several buoyancy-related research projects are examined.

1.2.1 Formal classroom instruction
Generally, students can memorise Archimedes’ Principle and solve quantitative buoyancy-related problems. Occasionally, some can even prove them mathematically without any difficulty. However, the underlying qualitative causal relationships between the entities are underplayed. Noticeably, the explanation for floating or sinking phenomena is linked to relative densities and seldom to relative magnitudes of weight and buoyant force (Raghavan & Glaser, 1994).

Typically, physical laboratory experimentation over-emphasises the verification of Archimedes’ Principle which requires students to run an experiment to confirm that the apparent weight loss of a totally or partially submerged object equals the weight of liquid displaced. Students can draw a few possible conclusions from the results of such an experiment. Firstly, if students merely focus on the perceivable concrete entities then there is a great likelihood that the apparent weight loss is linked to the weight of displaced liquid thereby bypassing buoyant force which cannot be directly observed. The second possibility is that students merely establish a relationship between buoyant force and weight of liquid displaced without probing further into the underlying causal relationships for the buoyant force. If they do, only a limited number of causal relationships can be derived from the mathematical expression of Archimedes’ Principle. They are causal dependencies of buoyant force on the immersed volume of object, the density of medium and the acceleration due to gravity. However, these relationships are under-emphasised.
in the normal curriculum. In addition, the kind of physical laboratory experience afforded in the normal curriculum is confined to a limited selection of concrete materials. This inadequacy has been highlighted by Raghavan and Glaser (1994). Consequently, students are deprived of an exploration-rich experience comprising a wide range of suspended objects and media whose attributes are manipulable for both the sinking and floating scenarios which could lead to a deeper appreciation of Archimedes’ Principle, and a better causal understanding of buoyant force. Therefore, the buoyancy domain designed for the purpose of this research aims to partially compensate for what the typical formal curriculum lacks by affording an extensive manipulation of variables as well as exploration of causal and non-causal dependencies for buoyant force. The full extent of the domain is furnished in Chapter 4.

1.2.2 Buoyancy-related research
The primary focuses of buoyancy-related research fall into three categories: documentation of students’ conceptions about floating and sinking, development of non-computer-based and computer-based curricula, or pedagogy. In the first category, we examine the main focus, scope and methodology of relevant investigations. For the ensuing discussion, the focus is on the inadequacies of non-computer-based as well as existing computer-based buoyancy-related curricula.

i. Documentation of students’ conception in buoyancy
Two broad categories of investigations have been conducted to uncover students’ conceptions of floating and sinking. The first category has an open format in which students are asked why an object floats or sinks. The core concept looked for in this kind of investigation is density or relative density. As for the second structured type of investigation, students are asked why an object floats or sinks in terms of the given referents: weight and buoyant force. Usually, research projects investigate students’ understanding of floating and sinking phenomena in terms of density or relative density (surface-level understanding), and rarely in terms of relative magnitudes of weight and buoyant force (deeper-level understanding).

The scope for investigating qualitative causal understanding of students in buoyancy is very limited with investigations predominantly addressing the causal factors for the flotation scenario (Biddulph & Osborne, 1984; Erduran & Duschl, 1995). Erduran & Duschl (1995) address the
causal factors for a floating vessel such as height of sides, volume, and bottom surface area. The factor of surface area should not have been presented as a stand-alone factor in the concept map drawn by Erduran and Duschl (1995) because it has to be integrated with the immersed depth of the object before a valid conclusion can be drawn. Two examples exemplify why the bottom surface area is not a stand-alone factor:

**Case 1**
If bottom surface area increases and immersed depth decreases more, then immersed volume of the floating object decreases and buoyant force decreases.

**Case 2**
If bottom surface area increases and immersed depth remains constant or increases, then the immersed volume of the floating object increases and buoyant force increases.

Only the interacting factors of the bottom surface area and immersed depth of the object yield a valid conclusion. Su Gang (1993; 1995) investigated students’ qualitative causal understanding for both the floating and sinking scenarios through interviews. The causal and non-causal factors are: horizontal versus vertical position of a block, solid versus hollow object, depth of submergence, material of object, and nature of the liquid. These students had not undergone any instruction in Archimedes’ Principle but had been taught about buoyant forces in fluids. Questions asked were direct, requiring a ‘yes’ or ‘no’ answer without a justification. Such a method of investigating students’ conceptions about the domain could be considered superficial as it fails to uncover the deep-seated causes of their incomplete or erroneous conceptions. Ways to probe students’ deep understanding of the domain are exemplified in Chapter 8.

The research reported in this thesis addresses issues relating to unveiling students’ conceptions about buoyancy. Previous research mainly focuses on pre-conceptions or children’s reasoning about floating and sinking. However, this research aims to shift the focus to adults who have been formally instructed about Archimedes’ Principle and buoyant force, with emphases on uncovering their buoyancy-related conceptual frameworks, and at the same time investigating how relevant prior knowledge is invoked when engaged in reasoning about floating and sinking phenomena.

The typical direct question approach for enquiry purposes, is replaced with a problem-solving approach in which students are encouraged to ‘think aloud’ while performing problem-solving tasks. Newell and Simon (1972) regard such information obtained as particularly useful in helping identify the students’ notion of ‘problem-space’ which is further described in Chapter 2. In addition, such tasks help unveil students’ misconceptions and faulty reasoning (Posner & Gertzog, 1982). Therefore, a problem-solving environment built for students’ exploration may
provide a richer as well as deeper insight into students’ reasoning about floating and sinking phenomena. The relevant categories of problems are described in Chapter 2.

As mentioned earlier, the scope for investigating causal qualitative understanding of buoyancy is very limited and can be superficial. This research aims to extend the notion of causal qualitative understanding in this domain by incorporating more causal as well as non-causal factors.

ii. Buoyancy curricula

Many non-computer-based buoyancy curricula that have been developed are entirely experiment-based (Biddulph & Osborne, 1984; Rowell & Dawson, 1977; Su Gang, 1993, 1995). They aim to facilitate learning through scientific inquiry which involves experimentation with concrete materials followed by generalisation. However, as mentioned earlier, such a form of physical exploration is constrained due to a limited range of concrete materials proffered. The design of computer-based curricula helps overcome such a limitation. However, only a few computer-based curricula have been developed for buoyancy. A quantitative curriculum has been developed to facilitate weight-density differentiation that leads to a prediction of whether an object floats or sinks Smith et. al, 1992; Snir et. al, 1995b). Once again, the conceptual understanding of buoyancy here is rather superficial because it hinges on the surface attributes of density or relative densities without addressing the underlying causes of the phenomena. The only causal relationship highlighted by Snir et. al (1995b) concerns the effect of the relative densities on the immersed depth of a floating object.

Raghavan and Glaser (1994; 1995) also developed a quantitative model-based curriculum for floating and sinking where the underpinning abstract concepts of weight, buoyant force, and net force are concretised. The first aim of their floating and sinking curriculum is to enable students to understand when and why an object floats or sinks in a liquid. Here, the ‘when and why’ understanding is anchored on the relative magnitudes of weight and buoyant force and whose imbalance yields a net force acting on the object. The second aim of the curriculum is the discovery of the causal dependencies of buoyant force on volume of body, and density of the liquid. Some of the inadequacies of the existing buoyancy curricula are addressed in the computer-based learning environments we have built.

1.2.3 Summary

In order to foster a more extensive yet deep understanding of buoyancy, there needs to be a shift from the typical ‘when and why’ understanding to qualitative causal understanding with emphases on rich exploration and discovery of causal as well as non-causal factors for buoyant
force. Computer-based learning environments designed for such purposes will be discussed in the next section.

1.3 Computer-Based Learning Environments

Computer-based learning environments which aim to promote a deeper understanding of buoyancy are designed in this research. Here, we discuss the essential features of these learning environments.

Qualitative laboratory simulations designed for the purpose of this research support constructivistic learning. The first simulated laboratory model resembles the set of apparatus employed for the verification of Archimedes’ Principle. The details of this model are furnished in Chapter 3. The second simulated model comprises simple, familiar objects with terms phrased in informal language so as to facilitate easy use and comprehension. Details of this model are described in Chapter 4. In this model, the intangible and abstract buoyant force is explicitly represented so that students can observe the causal or non-causal effects of a manipulated variable on the visual representation of buoyant force. In typical computer-based models for buoyancy, students manipulate a variable followed by merely observing whether the manipulation results in a floating or sinking phenomenon (Raghavan and Glaser, 1994; Snir et al., 1995b). However, the second computer-based learning environment designed for this research provides students with the opportunity to manipulate one or more variables and observe the multiple-linked effects of a progressive change of a model (object or medium) attribute. In addition, students can observe these causal effects for three differing situations: the sinking situation; during the switch from a sinking to a floating situation; and the floating situation. The details of such an exploration are described in Chapters 4 and 5.

Typical computer-based laboratory environments are data-driven. Often, students run experiments, collect quantitative data, transform them into pictorial representations, and abstract causal relationships from these representations. On the other hand, the learning environments in this research bypass the data collection procedure so that qualitative causal understanding can be focused on. Students manipulate a variable, run an experiment, and observe the results displayed in the form of qualitative graphs so that qualitative causal relationships can be abstracted from them.

The computer-based learning environments designed for the purpose of this research do not have any student nor expert domain model. Students are responsible for conducting self-diagnosis, error-discovery, and error-recovery. The model in the environment consists of familiar objects so
as to invoke relevant prior knowledge, and the novel problem-solving situations provide a workbench for integrating the invoked prior knowledge.

In this research, the first embedded pedagogy is grounded on the Socratic method so as to provoke students to probe beyond the perceptual features of the interface into the underlying principles governing the simulation. Considering the fact that buoyancy is a vocabulary-lean domain, we have employed a pictorial form of Socratic dialogue which solely employs pictorial counter-examples for feedback purposes. The details of its implementation are described and exemplified in Chapter 3. The second embedded pedagogy is the Articulation-cum-Reflection strategy which provides students with a tool to aid their articulation whilst exploring the system. The details of this strategy and the tool are given in Chapter 4.

The two learning environments in this research are hybrids of the simulated laboratory and problem-solving environments. The second learning environment comprises ill-structured problems (details are discussed in Chapter 2) where students invoke relevant prior knowledge to form hypotheses. However, these hypotheses cannot be tested. The aims underpinning the design of such an open environment are to unveil students’ buoyancy-related misconceptions (Chapter 7) and their faulty reasoning (Chapters 7 and 8).

In summary, the computer-based learning environments developed for this research are qualitative laboratory simulations which emphasise active exploration and qualitative causal understanding of buoyancy. The familiar yet novel problem-solving tasks are ill-structured in nature so as to invoke students’ relevant prior knowledge. Here, problem-solving is viewed as a search for a solution path (Newell & Simon, 1972) that will form a basis for evaluating students’ understanding of buoyancy. This is discussed in the next section.

1.4 Qualitative Understanding

Qualitative understanding, a higher-order learning outcome, is the central focus of this research. We adopt the notion of qualitative understanding as a semantic network of concepts linked by causal or non-causal relationships (Kayser et al., 1999). Here, the evaluation of qualitative understanding or the modelling of its changes is based on two criteria. Firstly, the problems are ill-structured so this means the end states have to be determined by students. Therefore the first criterion of evaluation is the correctness of these end states. The second criterion is the completeness or correctness of student causal explanatory models. These causal explanatory models consist of a set of entities that are abstracted from the results of the analysis of students’
search spaces. The details of the modelling and evaluation of qualitative understanding of buoyancy are explained and exemplified in Chapter 8.

1.5 The Aims of the Research
The research consists of two phases with two different systems. The first phase of the research aims to answer the following research questions:

i. Language
   What type of language do students employ for their reasoning?
   What are the language-related problems faced by students?

ii. Conceptions
    What is students’ causal understanding of buoyancy?
    How do students reason about buoyancy-related phenomena?

iii. Change
    What are the conceptual changes effected by the pedagogy called ‘Provoked Reflection Strategy’?

iv. Problems
    What are the problems faced by students when exploring the system?

The second phase of the research aims to answer the following research questions:

i. Articulation
   How do students articulate?
   What do they articulate?

ii. Reasoning
    How do students reason?
    What do they reason with?

iii. Change
    What are the observed conceptual changes effected by the pedagogy known as ‘Articulation-cum-Reflection’?

1.6 The Outline of the Thesis
Chapter Two
This chapter provides the framework for the buoyancy domain, documents students’ buoyancy-related conceptions uncovered by previous research, describes existing model-based curricula for buoyancy, and the technological, psychological, and pedagogical foundations of the research.
Chapter Three
This chapter documents the needs analysis conducted prior to the development of the Spring Balance System, and describes its design as well as implementation. This is followed by a description of the formative evaluation for the Spring Balance System and a discussion of the results of this evaluation.

Chapter Four
The main focus of this chapter is the BSL (Body-String-Liquid) System. It describes the system design and implementation which includes its foundations, essential features of the interface, and functionality of the system. The procedures and results of a formative evaluation are also discussed.

Chapter Five
This chapter describes the experimental study conducted with the BSL System including excerpts of a student’s transcript to exemplify the conduct of the experiment.

Chapter Six
The main focus of the first part for the analysis of empirical evidence is articulation. The results and discussion for students’ articulation process as well as content are presented in this chapter.

Chapter Seven
The main focus of the second part for the analysis of empirical evidence is reasoning. It presents findings relating to the reasoning strategies employed for the floating and sinking situations followed by the level of precision for their qualitative reasoning.

Chapter Eight
The main focus of the third part for the analysis of empirical evidence is conceptual change. This chapter presents evidence of changes in terms of theory framework, schema framework, and mental model.

Chapter Nine:
This chapter presents a summary of the findings, a summary of emergent issues, and implications of this research.

Chapter Ten
This chapter critiques this research methodology and offers suggestions for further work.