Chapter 10
Critique and Future Work

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Chapter 10

Critique and Future Work

10.1 Critique of the Research

A number of criticisms could, on reflection, be made of the research methodology:

a. Interface

The Spring Balance System provides a student with the opportunity to run an experiment and observe its results. However, during the pilot test, students had problems identifying the scale and string in the simulated laboratory model due to its low physical fidelity. Consequently, real physical objects have to be mapped onto their corresponding representations in the interface. This problem would not have occurred if a virtual reality environment has been built for the Spring Balance System.

The levels of discovering principles in the Spring Balance System are illustrated in Figure 10.1. The first level is the observable surface level while the second is a deeper intangible level where the underlying principle of buoyant force governs.

![Diagram of Levels of Discovery](image)

Figure 10.1: Levels of discovery

The principle to be discovered for the first level is the causal effect of the volume of immersion (or its rate of change) on the reading of the spring balance (or its rate of change) which is
represented by a graph. However, the main goal of the system is that students discover the underpinning Archimedes’ Principle which relates volume of immersion (or its rate of change) and buoyant force (or its rate of change). However, in Chapter 3, the rule uttered was ‘rate of surface area change’ rule which could be attributed to the two-dimensional representation of the simulated laboratory model. Likewise, in Chapter 7, the incorrect two dimensional-based derived surface area rule is most frequently applied for L instead of the correct three-dimensional-based immersed volume rule. Therefore, in conclusion, these erroneous area-related derived rules might be due to the two-dimensional representation of the simulated laboratory models. The derived rules could have been different if the two-dimensional models are replaced with three-dimensional ones.

For Task 6 (Volume of Immersion) of the BSL System, the initial model displayed is a fully submerged body. The positions of the starting ellipses BSL on the graph correspond to the magnitudes of BSL in the model. Students are requested to predict the BSL graphs for an increasing immersed volume of the body. This could cause confusion because the positions for the starting ellipses BSL are for a situation with a maximum volume of immersion. Consequently, this is probably the reason why evidence in Chapter 6 shows that student S1 demonstrated an increased amount of articulation due to a model-related problem for Task 6 (Volume of Immersion).

The BSL System allows concurrent manipulation of more than one variable in the Problem-Solving Stage. An unrealistic representation of the model will occur for the following combined manipulation: Width of Body (decrease) and Height of Body (increase). When the experiment is run, the laboratory and equilibrium of forces models, and the matched graphs will change accordingly. It will reach a certain point when Arrow B keeps increasing even though the width of the body visually appears to be zero on screen. However, theoretically, the width of the body is very small but does not equal zero.

b. Feedback
In the Problem-Solving Stage, the exploration of the causal effects of several variables on BSL (for the sinking domain) is met with direct immediate feedback. On the other hand, for the floating domain, inference about the causal relationships has to be made from graphs. Inferring from indirect delayed feedback is difficult and particularly when more than one manipulation occurs at the same time. This is supported by evidence in Chapter 8 which indicates some negative changes in causal relationships for BSL in the floating domain when students explore
the Problem-Solving Stage of the system. Results would have been different if students were given direct feedback for the floating domain.

One of the aims of the Questions Stage of the BSL System is to gain insight into students’ misconceptions, faulty reasoning and also bases of the derivation of their scientific rules. Consequently, an ill-defined problem-solving environment is designed for such a purpose. This type of environment does not facilitate hypothesis testing that could lead to repair. Probably, this is the reason why some consistently incorrect rules are being applied almost throughout the entire exploration.

The Problem-Solving Stage of the system only emphasises causal relationships. Feedback given relates only to causal relationships. This is also true of the predicted solutions. Consequently, students are not given appropriate experiences to refine their causal explanatory models. This is probably the reason why students’ explanatory models remain incomplete and incorrect till the end of the experimental session.

10.2 Future Work

A number of suggestions could be made from this research:

a. Extension of the pedagogy

Evidence in Chapter 3 shows that the two approaches of the ‘Provoked Reflection Strategy’ could provoke students to reason and reflect on their derived rules. However, the environment only provides a single problem and a single solution graph situation. Further work could be undertaken to explore the feasibility of implementing the ‘Provoked Reflection’ strategy in a situation with a single problem but multiple solution graphs.

b. Extension of tools

Evidence in Chapter 6 reveals the correct use and misuse of the Articulation-cum-Reflection Tool. Here, misuse is due to ambiguity or misinterpretation of the contents of the tool. Therefore, before the tool can be re-employed, it is suggested that steps be taken to overcome the problem of its misuse. In Chapter 4, the listed characteristics of the tool are: use of simple and object-related (to invoke spontaneous concepts) terms, and definitions phrased in lay terms (to facilitate easy understanding of scientific concepts). This suggested list of characteristics can form the basis of developing articulation tools for other domains.

As discussed in Chapter 3, the aim of the developed graphing tool is to enable students to represent their solutions in qualitative Cartesian graphs. The nine graph segments provided in this tool facilitate an easy and quick creation of qualitative composite graphs. In addition, it also
fosters a more precise representation of solutions because it allows students to reason with the second order of precision without having to bother about the formalisms of calculus. As discussed in the same chapter, the list of criteria for the evaluation of qualitative composite graphs are: starting and end point of the graphs, gradients for linear graphs, degree of convexity or concavity for curves, length of segments, and the sequence of the graph segments. The graph segmentation concept can be used as a basis for the development of a computational model for the evaluation of qualitative composite graphs. The graphing tool and graph segmentation concept can be applied to other systems which incorporate qualitative graphs as a form of external representation.

c. **Extension of the data analysis**
The BSL System is an example of an ill-defined problem-solving environment with given multiple initial states and non-given multiple end states. The data analysis conducted in Chapter 8, pertains to correctness of the individual end states, and also the completeness as well as correctness of the solution paths. Further work could be done by analysing students’ problem-solving strategies and behaviour in such a type of problem-solving environment.

d. **Extension of the design of the system**
It would be beneficial if the current two-dimensional environment of the Spring Balance System and BSL System was replaced with a virtual reality environment. This would help enhance the physical fidelity of the interface and foster a better and more precise perception of the surface structure of the simulated laboratory models.

The Spring Balance System only has an embedded one-way causal model. Students manipulate the model and predict the causal effects on the graph or the tutor manipulates the model and the system displays its corresponding solution graph. In order to promote a better understanding of causal effects, it is suggested that the one-way causal model be extended to a dual-way causal model. With this facility, students will be able to observe the effect of a change in the model on the solution graphs and vice versa.

As discussed in Chapter 3, the human tutor is responsible in evaluating the correctness of the graphs, diagnosing errors, and prescribing one of the DPSS or SPDS approaches in the event of an error. When the prescription is done manually, it incurs cognitive and information processing load for a human tutor. Let’s take the example of Figure 10.2, which is the exact replica of Figure 1 of Appendix C.
When this erroneous predicted graph appears, a human tutor takes the following course of actions:

i. Spot where the error is
ii. Select DPSS or SPDS (in this case it is DPSS)
iii. Choose a shape that will produce a curve (possibly, inverted cone, upright cone, horizontal prism, or sphere). In this case the curve denotes an ‘increase which decreases with time’ so the inverted cone is more appropriate
iv. Decide on the initial conditions of the model (an inverted cone): no immersion, half immersion or complete immersion (in this case it is complete immersion)
v. Decide on the motion of the model: upwards or downwards (in this case it is upward motion)

A simulated tutor will certainly help reduce an experimenter’s memory and cognitive load during the implementation of the Spring Balance System. Therefore, the design of the system should be further extended to incorporate a simulated tutor that can undertake the diagnosis, and prescription responsibilities of a human tutor.

Chapters 7 and 8 have revealed evidence of students’ misconceptions and faulty reasoning when they explored the activities in the BSL System. This means that future systems can be built on these findings. In addition, since the BSL System is no longer needed to provide insights into students’ reasoning about buoyancy, its design should be extended to cater for a testing facility. With this facility, students will be able to test their derived rules so that repair could take place.

The BSL System provides a platform for the acquisition of causal relationships for BSL. The design of the BSL System could be extended to include a real life-like problem-solving environment for students to apply their acquired principles.
In Chapter 8, findings reveal that generally, student causal explanatory models are incomplete. It is suggested that tasks that could help students to refine their causal explanatory models should be incorporated into the design of the Problem-Solving Stage of the BSL System. Another alternative is to include explanatory templates for the Questions Stage. Students will be required to fill in the empty templates during justification. The opportunity to modify or delete the templates will also be given. Students could also set the values of some of the nodes or operators in the templates as default if they are recurrent. This can reduce the tedium of having to repeatedly fill up a node with the same thing. For example, ‘\( g \)’ which occurs repeatedly for B and L.

10.3 Conclusions
This research primarily aims to investigate whether a computer-based learning environment grounded in sound pedagogical, psychological, and technological foundations, could foster a better qualitative understanding of buoyancy. The systems built for this purpose are hybrids of the qualitative laboratory and problem-solving environments which support constructivist learning through active exploration and reflection.

The Spring Balance System is the first system designed for the purpose of this research. It allows students to run and observe an experiment. Qualitative Cartesian graphs are employed for students to represent their solutions. Indirect feedback is prescribed through the ‘Provoked Reflection’ strategy which is grounded on the Socratic method. The pictorial Socratic dialogue conducted aimed to provoke students to probe through the perceptual structural features of the problem and solution, into the deeper level of the simulation where Archimedes’ Principle governs. An analysis of findings for the first phase of pilot testing suggested that students were generally language deficient. Consequently, a prototype version of an articulation tool was developed and tested during the second phase of pilot testing. Results suggest that the ‘Provoked Reflection’ strategy with this articulation tool effected positive conceptual changes. In addition, students found it rather difficult to reason with a resultant force (the reading of the spring balance).

The design of the BSL System addressed the inadequacies of its predecessor. Firstly, an Articulation-cum-Reflection Tool with simple and object-related terms was incorporated into the design of the BSL System. The equilibrium of forces (BSL) model helps to reduce cognitive load because it enables students to reason about each individual force and also in the light of the other two. An analysis of findings revealed that generally, the usage of the articulation tool decreased with time. The types of reasoning strategies employed by students were: Experiential Reasoning,
Common-sense Reasoning, Scientific Reasoning, and BSL Reasoning. Some of the underlying causes of their faulty reasoning were: influence of prior knowledge, erroneous conception of target concepts, propagation of errors (in chained reasoning) and overemphasis of surface-level perception of a situation. Evidence suggests that undergoing a series of tasks seemed to facilitate a repair of faulty conceptions. However, an analysis of students’ problem space revealed that student causal explanatory models were generally incomplete and devoid of essential concepts that constitute Archimedes’ Principle. In conclusion, the Articulation-cum-Reflection strategy is successful in effecting some form of learning.