Pictorial Socratic Dialogue and Conceptual Change

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Abstract

Counter-examples used in a Socratic dialogue aim to provoke reflection to effect conceptual changes. However, natural language forms of Socratic dialogues have their limitations. To address this problem, we propose an alternative form of Socratic dialogue called the pictorial Socratic dialogue. A Spring Balance System has been designed to provide a platform for the investigation of the effects of this pedagogy on conceptual changes. This system allows learners to run and observe an experiment. Qualitative Cartesian graphs are employed for learners to represent their solutions. Indirect and intelligent feedback is prescribed through two approaches in the pictorial Socratic dialogue which aim to provoke learners probe through the perceptual structural features of the problem and solution, into the deeper level of the simulation where Archimedes' Principle governs.

Keywords: **Articulation, conceptual change, modelling, qualitative reasoning, reflection, Socratic dialogue**

1 Introduction

Socratic dialogue is a dual-way communication between a tutor and a learner. The tutor does not teach a subject by direct exposition (Wenger, 1987). Instead, the learner's belief is challenged through a series of questions which lead him to reflect on his own beliefs, induce general principles, discover gaps and contradictions in his beliefs, and thereby revise his beliefs. Examples of Socratic dialogic systems are WHY (Stevens & Collins, 1977) which aims to guide a learner's reasoning process dialogues, and TAP (Wong et al. 1998), to help learners develop systematic reasoning through the formulation, testing, and debugging of hypotheses. However, the problem that arises in such systems with natural language dialogues is their limited processing capability. Thus, we propose a pictorial Socratic dialogue, an alternative way of conducting a Socratic dialogue. The phrase 'Pictorial Socratic Dialogue' has been coined to refer to a Socratic dialogue involving only graphics (e.g drawings of objects or Cartesian graphs).

In this paper, we shall first describe a qualitative simulated laboratory model. This is followed by the discussion of approaches employed in the pictorial Socratic dialogue and their effectiveness in fostering a better understanding of buoyancy.

2 Spring Balance System

The prototype for the Spring Balance System is an unintelligent system because it has neither an expert module nor a learner module. However, the experimenter assumes the role of a tutor who prescribes immediate and intelligent feedback based on the Socratic method. In the Spring Balance System, qualitative Cartesian graphs are used as a form of external representation which learners use to represent their predicted solution. The direct manipulation feature incorporated in the design of the interface allows learners to manipulate the model through button clicks and also modify the shape of each graph directly. A multiple-linked representation feature that links the laboratory model to the graph aims to help learners perceive a link between the two and thus establish some patterns about the link. In this section, we shall describe the laboratory model in the Spring Balance System, as well as graphing and manipulation tools.

2.1 Qualitative laboratory model

The Spring Balance System models a set of experimental apparatus that is typically employed for the verification of Archimedes' Principle in a physics laboratory. As depicted in Figure 1, this simulated laboratory model comprises a spring balance with a pointer but a non-calibrated qualitative scale, an object suspended from the spring balance, and a container filled with an incompressible as well as infinite liquid.

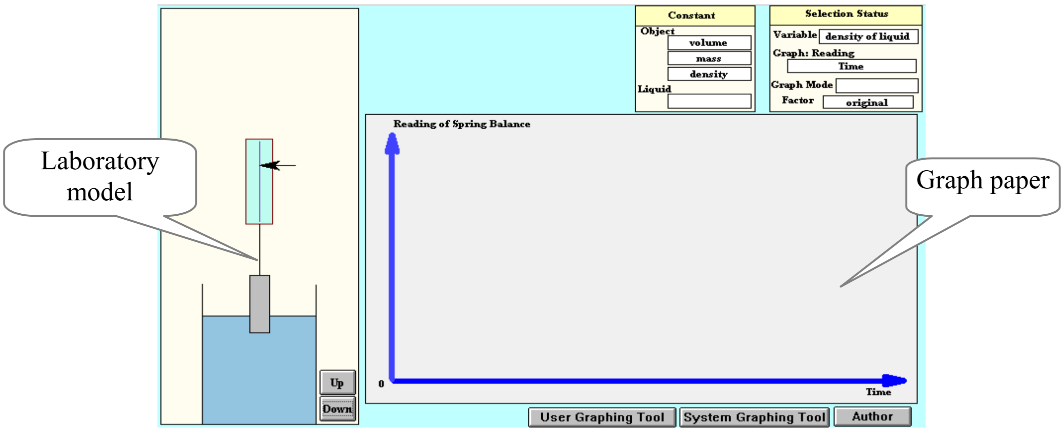


Figure 1: Interface for the Spring Balance System

2.2 Graphing tool

The *graph paper* consists of a two-dimensional qualitative graph which is depicted in Figure 1. The y-axis is labelled as *Reading of Spring Balance* while the x-axis is *Time*. The user graphing tool provides nine graph segment icons shown in Figure 2. Relevant segment icons are clicked to create a composite graph which basically constitutes a series of segments.

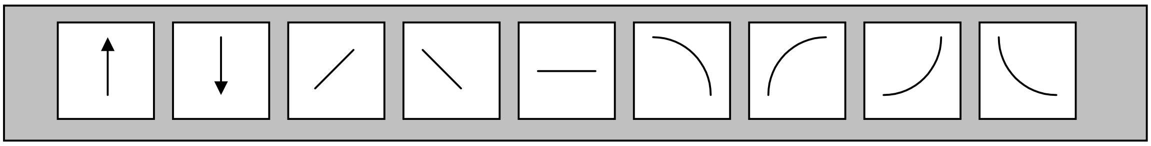


Figure 2: Graph segment icons for the creation of composite graphs

There are several reasons for providing such a type of user graphing facility. Firstly, it facilitates the pictorial Socratic dialogue which shall be discussed later in this paper. Secondly, the inadequate vocabulary of qualitative reasoning constrains a more precise qualitative description of the dynamic system behaviour. However, with the provision of the nine graph segment icons, learners can reason qualitatively with a higher order of precision without having to consider the formalisms of calculus. Table 1 shows a comparison of qualitative reasoning with natural language and qualitative graph segments.

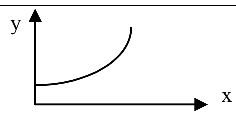
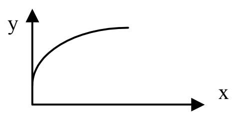
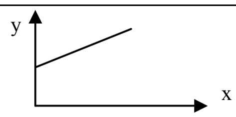
Natural language	Cartesian graphs
If x increases then y increases with a steady increasing rate of increase	
If x increases then y increases with a steady decreasing rate of increase	
If x increases then y increases with a constant rate of increase	

Table 1: Qualitative reasoning with a higher order of precision

Based on Table 1, it is obvious that the natural language form of qualitative reasoning with a higher order of precision is rather clumsy and incurs information processing load. On the other hand, qualitative reasoning with graphs is elegant and also facilitates easy and quick abstraction of the causal relationships between the entities.

2.3 Manipulation tool

The Spring Balance System allows only one variable to be manipulated at a time for a particular experiment so that learners could focus on only one causal effect. The two main components in the *Manipulation tool* are *Variable* and *Factor*. The attributes of the object or liquid that can be varied are: *Density of Liquid*, *Density of Object*, *Width of Object*, *Height of Object*, or *Shapes*. The various shapes provided for exploration are illustrated in Figure 3. The menu *Factor* enables the learners to choose a qualitative quantum of change associated with a variable opted for. The five items in this menu are: *Very small*, *Small*, *Original*, *Great*, and *Very great*.

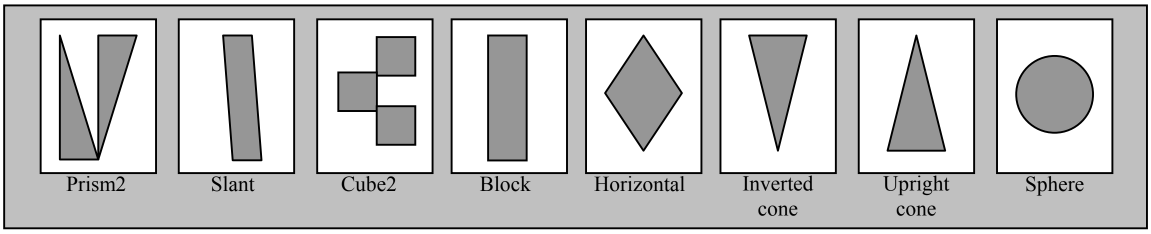


Figure 3: Various shapes of object

3 Feedback prescription

For this prototype stage, when learners' predicted solutions are erroneous the pictorial Socratic dialogue is implemented. This strategy aims to stimulate the learners to probe beyond the perceived structure of the environment, into a deeper level of abstraction where the underlying principles of the simulation are. The pictorial Socratic dialogue encompasses two approaches that are closely related to those of Lepper et al. (1993). The first approach is the 'Different Problem and Similar Solution Approach' while the second one is the 'Similar Problem and Different Solution Approach'.

3.1 'Different Problem and Similar Solution (DPSS) Approach'

Let us imagine this scenario. A problem is created and the learner's predicted solution graph is erroneous. The tutor creates a new problem. This problem has a solution that is similar to the learner's erroneous solution. However, it is different from the original problem because both have different correct solutions. The four mappings learners are expected to conduct are: the original problem to the learner's erroneous solution; the learner's erroneous solution to the correct solution for new problem; the new problem to its correct solution; the original problem to the new problem. The illustration for this approach is shown in Figure 4.

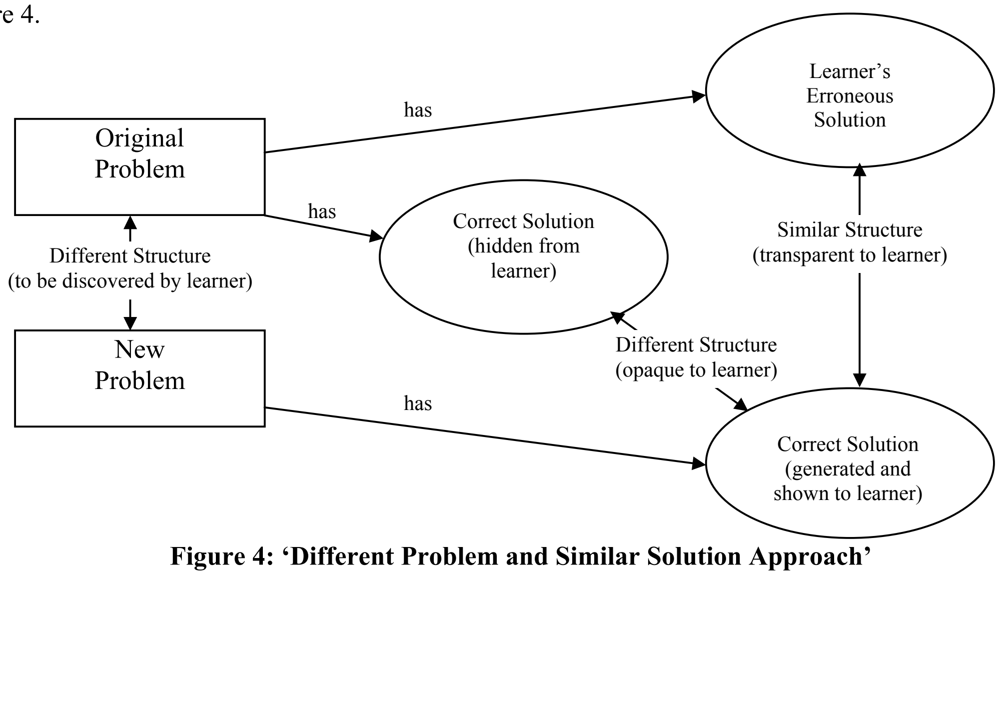


Figure 4: 'Different Problem and Similar Solution Approach'

3.2 'Similar Problem and Different Solution (SPDS) Approach'

In this approach, the new problem is similar to the original problem because both have similar correct solutions. However, the learner can only view his own erroneous solution and the correct solution for the new problem whereby both obviously have different structures. This approach is illustrated in Figure 5. Learners are also expected to reflect on the four mappings that have been listed earlier.

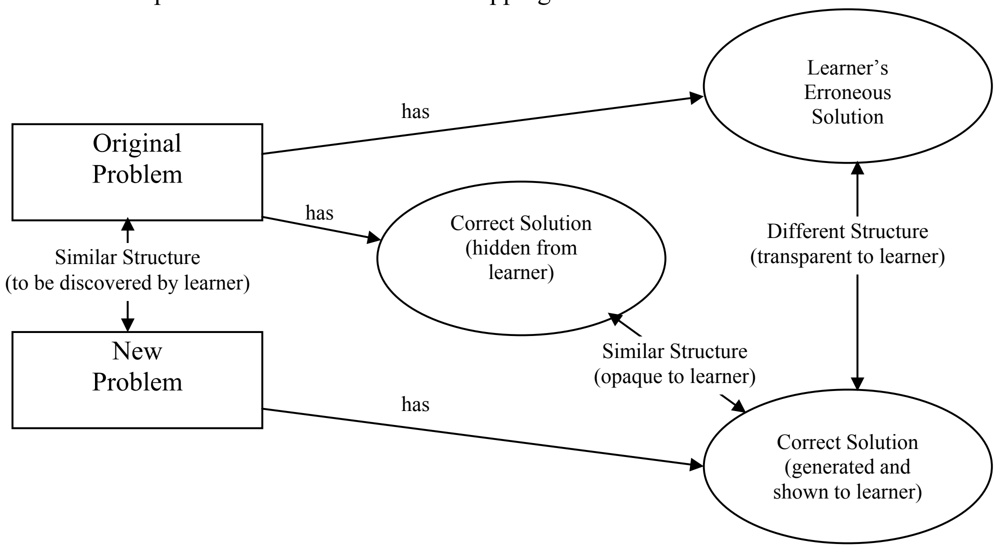
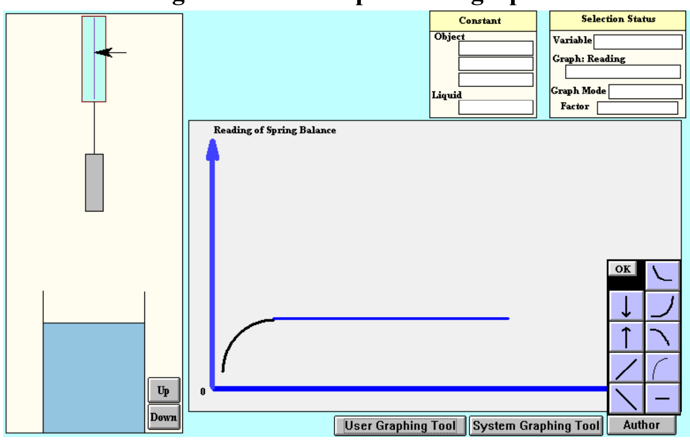


Figure 5: 'Similar Problem and Different Solution Approach'

3.3 An example for the implementation of the DPSS and SPDS approaches

The first problem presented to a learner was a cuboid which was initially above the liquid surface. It was then lowered until it was fully submerged in the liquid. The first solution predicted by the learner is shown in Figure 6.

Figure 6: Student predicted graph 1



The tutor implemented the DPSS approach by changing the shape of the object (cuboid to inverted cone) and set the initial condition where the inverted cone was fully immersed and just beneath the liquid surface as in Figure 7. As the inverted cone was raised out of the liquid (from 'full immersion' to 'no immersion'), a graph was automatically and simultaneously generated by the system (see Figure 8). The learner was asked to compare Figures 6 and 8. The learner reflected on his predicted solution and revised his solution (see Figure 9).

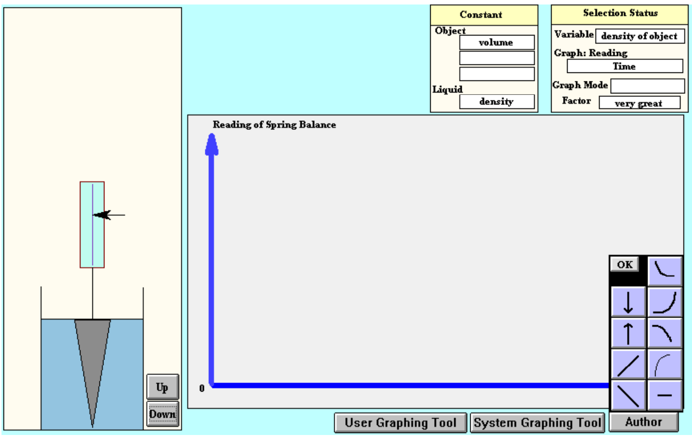


Figure 7: Initial conditions for system generated graph 1

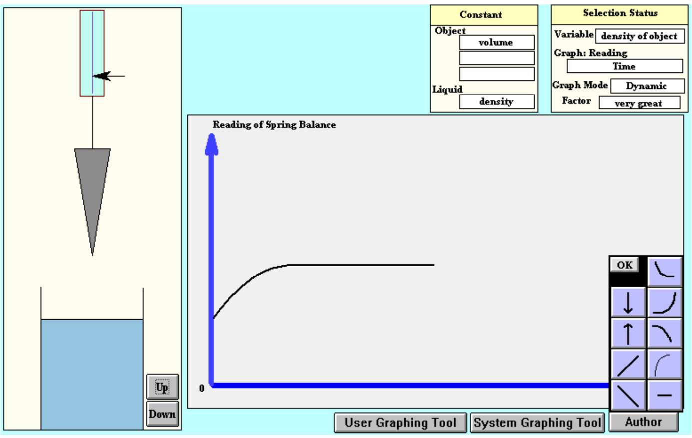


Figure 8: System generated graph 1

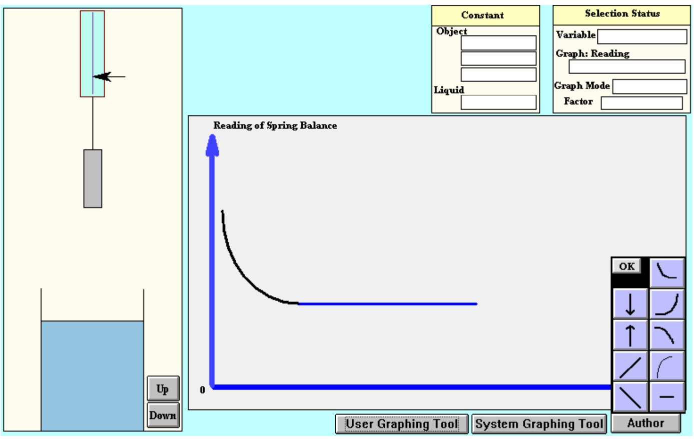


Figure 9: Student predicted graph 2

The experimenter implemented the SPDS approach by changing the shape of the object. A composite shape, comprising two prisms, and having the same correct solution as the cuboid, was selected for a new experiment. When the experiment was run by lowering the composite shape into the liquid (from 'no immersion' to 'full immersion'), the automatic and dynamic graph generated was as shown in Figure 10.

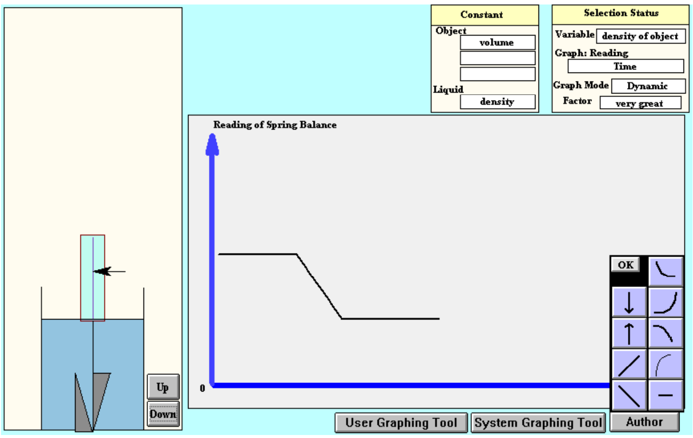


Figure 10: System generated graph 2

4 Experimental studies

Two experimental studies were conducted to investigate whether the pictorial Socratic dialogue effected any conceptual change.

4.1 First study

The participants for the first study were three postgraduate research students, and one final civil engineering undergraduate student. The experimental design was a pre-test–treatment–post-test design. The materials used for the experiment were: the Spring Balance System, worksheet, audio-tape, pre-test and post-test probes.

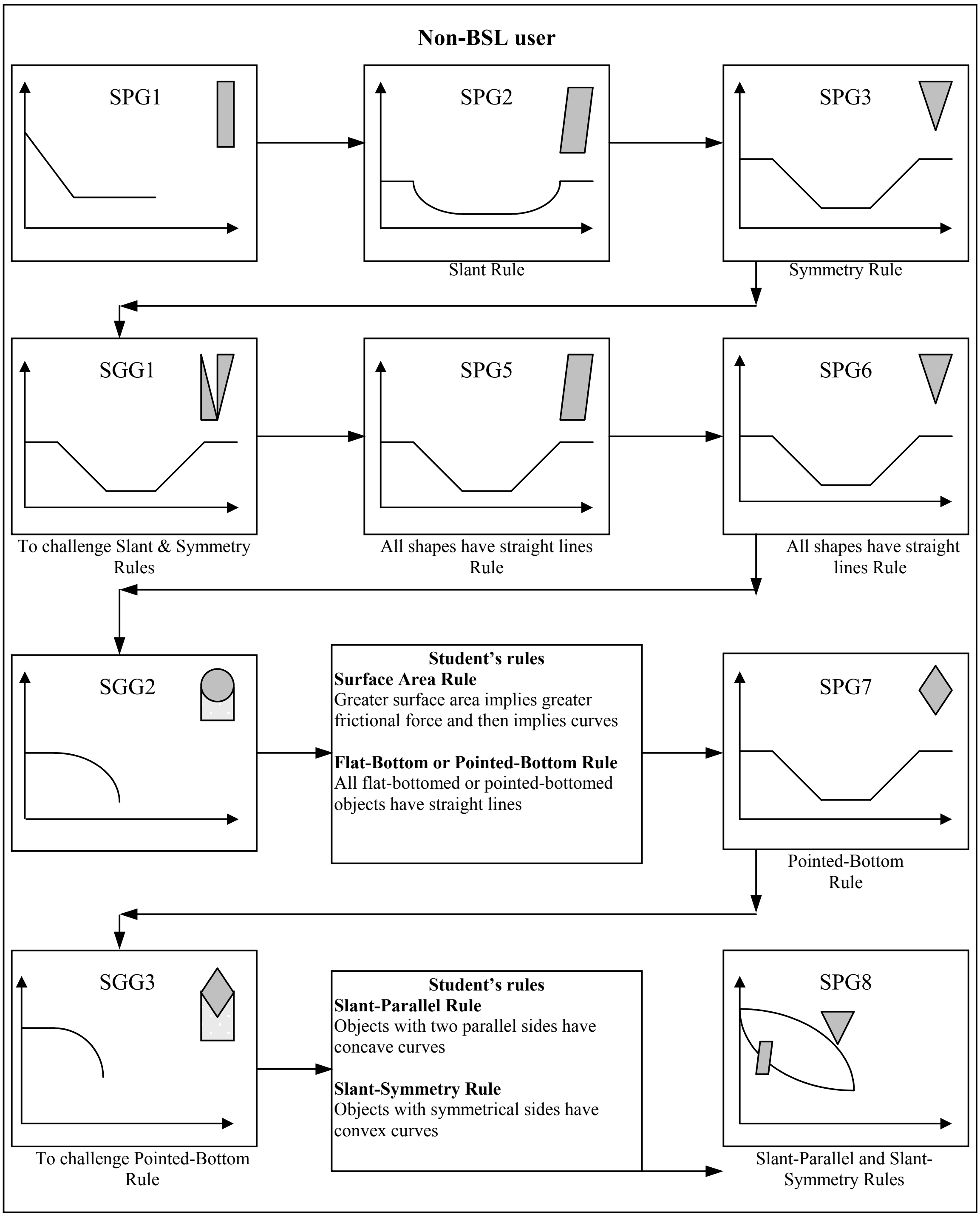
In each experimental session, the learners first ran the experiment without the generation of a graph, followed by predicting the graph for the *Reading of Spring Balance* against *time*. A predict-justify-test strategy was implemented where the learners hypothesised, justified, and tested their hypotheses. The predicted solution was evaluated by the tutor. An indirect and immediate intelligent feedback in the form of a counter-example was prescribed by the tutor so as to effect cognitive dissonance which could provoke reflection.

4.2 Second study

In the first study, some students had difficulty justifying their predicted solutions due to language deficiency. Thus, this called for the need to design and provide an articulation tool. This articulation tool contains simple object-related lay terms for the forces involved in the laboratory model. They are: **B**-**B**ody Force for weight; **S**-**S**tring Force for tension; **L-L**iquid Force for buoyant force (Self et al. 2000; Kor, 2001). The participants for this study were two high school boys and the methodology remained the same except that these participants were given the articulation tool.

5 Results and discussion

The participants for the first experimental group are called non-BSL users (because they were not provided with the articulation tool) while the second group, the BSL users. (BSL stands for **B**ody-**S**tring-**L**iquid). The types of conceptual change that are examined here relate to accuracy and consistency of prediction, rules of prediction and responses to pre-test and post-test probes. The relevant changes that occur within the non-BSL users are compared with those of the BSL users.

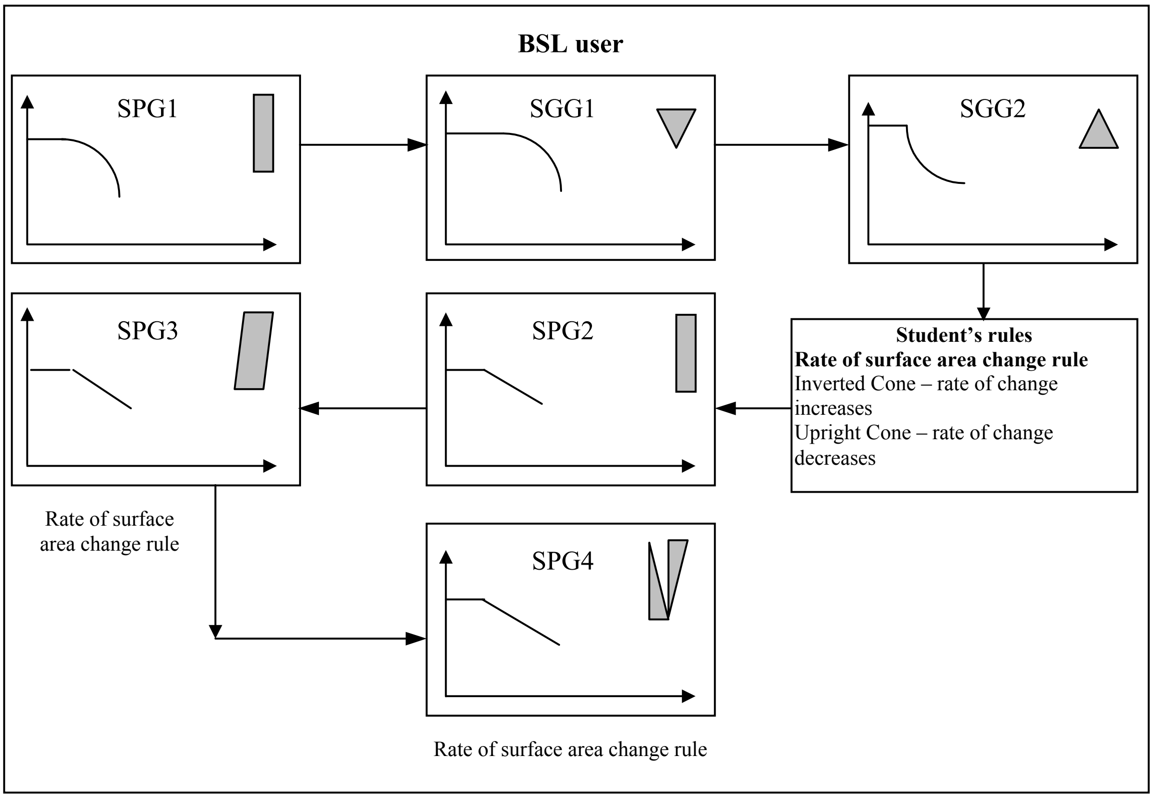


Note: SPG stands for 'Student Predicted Graph and SGG stands for 'System Generated Graph'. The number printed after these abbreviations denotes its order. The object at the right hand corner of each box denotes the shape of the object used for the experiment run. In all cases except for SGG2 and SGG3, the condition for the experiment is from 'no immersion' to 'full immersion' to 'no immersion' again. In SGG2 and SGG3, the condition for the experiment is from 'partial immersion' to 'full immersion'.

Figure 11: A series of Student Predicted and System Generated Graphs for a non-BSL user

Figures 11 and 12 display a series of student predicted and system generated graphs for a non-BSL user and a BSL user. The shape at the top right corner of each graph represents the shape of the object for the particular experiment. The studies suggest that the pictorial Socratic dialogue is more likely to effect a positive change in the predicted graphs of BSL users than of non-BSL users. This is exemplified by the series of graphs displayed in Figure 12. They are accurate and consistent after two system generated graphs. The prediction rule consistently employed is the rate of surface area change rule. As for non-BSL users, the pictorial Socratic dialogue seems to effect reflection which is demonstrated by the constant revision of predicted graphs and prediction rules in Figure 11. However, it does not seem to effect the type of intended positive change because non-BSL users overemphasise the perceptual structures of the model such as slants, symmetry, flat or pointed bottom of the object, and their effects on the shape of the graphs. A general conclusion that can be drawn is that the pictorial Socratic dialogue coupled with the articulation tool seems to effect a positive conceptual change.

Results show that non-BSL users demonstrate no marked changes in their pre-test and post-test responses. On the other hand, most of the BSL users' responses show a more positive change in their responses. This suggests that the articulation tool coupled with the pictorial Socratic dialogue effect learning.



Note: SPG stands for 'Student Predicted Graph and SGG stands for 'System Generated Graph'. The number printed after these abbreviations denotes its order. The object at the right hand corner of each box denotes the shape of the object used for the experiment run. In each case, the condition for the experiment is from 'no immersion' to 'full immersion'.

Figure 12: A series of Student Predicted and System Generated Graphs for a BSL user

6 Conclusions

In the Spring Balance System, pictorial Socratic dialogue is implemented for the prescription of indirect feedback for an erroneous predicted solution. However, this pedagogy alone seems to provoke only surface level reflection. This is evident when the non-BSL users overemphasise the perceptual structure of the problem. Rules applied are model-based. Some examples are rules which relate to the slant of sides, flat-bottom versus pointed tip of the body or shapes of body. On the other hand, when the pictorial Socratic dialogue is coupled with the articulation tool, it seems to provoke the intended positive reflection. Learners are made aware of the underlying critical entities (BSL) of the simulation. They merely focus on the causal relationships of BSL followed by integrating their effects. Reflecting on the explicit critical entities, BSL, leads to the discovery of the 'rate of change in surface area rule'. The imprecision of this rule is probably due to the two-dimensional representation of the simulated laboratory model. Despite its imprecision, this rule has almost consistently yielded correct predicted solutions for subsequent shape-related tasks. In conclusion, we suggest that the pictorial Socratic dialogue is ineffective when learners have to undergo two levels of discovery: firstly, to discover the underpinning critical entities, and secondly, to reason about their individual causal relationships followed by integrating their effects when predicting about the reading of the spring balance which is a resultant. Coupled with the articulation tool, the underlying critical entities are made explicit for students to talk and reason about and thus probably contribute to the effectiveness of the pedagogy.

As discussed earlier, 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. 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.

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