Chapter 4 The BSL System

4.1 Introduction .................................................................................................................. 71
4.2 System Design and Implementation................................................................. 71
  4.2.1 Introduction......................................................................................................... 71
  4.2.2 Conceptual model of the BSL System ............................................................. 71
  4.2.3 General description of the interface ............................................................... 74
  4.2.4 Functionality of the BSL System ................................................................. 78
  4.2.5 Conclusion...................................................................................................... 91
4.3 Formative Evaluation ................................................................................................. 92
  4.3.1 Aims.............................................................................................................. 92
  4.3.2 Expert appraisal ............................................................................................. 92
  4.3.3 Try-out session .............................................................................................. 92
  4.3.4 Summary....................................................................................................... 92
4.4 Conclusions ................................................................................................................. 92

Figure 4.1: Foundations for the design of the BSL System .............................................. 72
Figure 4.2: Navigation structure of the BSL System ..................................................... 75
Figure 4.3: Laboratory models ..................................................................................... 76
Figure 4.4: The equilibrium of forces model ............................................................... 76
Figure 4.5: Qualitative graphs ..................................................................................... 77
Figure 4.6: Sequence of students’ interactions in the Introduction Stage ...................... 79
Figure 4.7: Manipulation of B ..................................................................................... 80
Figure 4.8: Manipulation of B ..................................................................................... 81
Figure 4.9: Screen display after manipulation of L ...................................................... 81
Figure 4.10: Student’s sequence of actions for sinking situations with 2-D graphs ......... 83
Figure 4.11: Run an experiment without feedback ...................................................... 83
Figure 4.12: Creation of predicted graphs ................................................................. 84
Figure 4.13: Student’s sequence of student actions for sinking situations with 1-D graphs 85
Figure 4.14: Sequence of student-system interactions for real problem-solving tasks .... 86
Figure 4.15: Creation of a problem with a real situation (S>0) ..................................... 87
Figure 4.16: Creation of unreal and modified real target graphs ................................. 87
Figure 4.18: Manipulation Tool .................................................................................. 89
Figure 4.19: Problem-solving process for real target graphs ....................................... 89
Figure 4.20: Solution for modified real target graphs .................................................. 89
Figure 4.21: Generated matched graphs (in white) ..................................................... 89
Figure 4.22 Experiment run for modified real target graphs (with sinking and floating situations) ................................................................. 90
Figure 4.23: Comparison of real target and matched graphs ..................................... 91

Table 4.1: Differences between the Spring Balance System and the BSL System ........... 73
Table 4.2: Articulation-cum-Reflection Tool ............................................................... 77
Table 4.3: Sinking and floating tasks of the Questions Stage ...................................... 82
Chapter 4

The BSL System

4.1 Introduction
Language deficiency uncovered during students’ exploration with the Spring Balance System motivated the design and implementation of a new system, the BSL System. B stands for Body, S represents String, and L is for Liquid. However, in this thesis, BSL denote their respective forces. Just like its predecessor, the primary aim of the BSL System is to evaluate the effectiveness of an embedded pedagogy, Articulation-cum-Reflection strategy, in fostering students’ better understanding of buoyancy. In addition, it also aims to uncover how students reason about the phenomena in the domain.

This chapter describes the design and implementation of the BSL System followed by its formative evaluation, and a revision of its interface. This sequence of events resembles that of its prototype.

4.2 System Design and Implementation

4.2.1 Introduction
The BSL System is an interactive learning environment anchored on constructivism which promotes active construction of knowledge through exploration. The embedded pedagogy is learning through Articulation-cum-Reflection in a problem-solving context that aims to invoke students’ prior knowledge.

This section compares and contrasts the BSL System with its prototype, and briefly discusses the foundations of the BSL System. In addition, it describes the features of its interface followed by the functionality of the system.

4.2.2 Conceptual model of the BSL System
In Figure 4.1, one of the bases for the design of the BSL System is the feedback from the experimental session with the Spring Balance System. The feedback obtained from the experimental session with the prototype relates to language-deficiency, the simulated model, misconceptions, and pedagogy. As mentioned in Section 3, generally, students found it difficult to articulate their thoughts when asked to justify their solutions. Consequently, an Articulation-cum-Reflection Tool is provided in the BSL System. The details of this cognitive tool are given in the next section.
The laboratory model in the Spring Balance System is dynamic thus resulting in many distractions such as viscosity, resistance and even terminal velocity even though it is not a free-fall phenomenon. As discussed in Chapter 3, reasoning with a resultant force as indicated by the reading of a spring balance is rather difficult. To overcome this cognitive load problem, the BSL System provides the resultant force, $S$, alongside its two components, $B$ and $L$, in order that students can reason about each force individually or in the light of the other two.

Some of the misconceptions uncovered during the prototype sessions are misconceptions relating to shapes of objects, density of object or liquid. Therefore, it is the interest of this part of the research to investigate more extensively students’ misconceptions relating to causal and non-causal factors for buoyant force in the floating and sinking domain.

The results of the ‘Provoked Reflection Strategy’ in Chapter 3 seem to show that students overemphasise the surface structure of the model instead of probing deeper into the underlying principles of the domain. However, evidence in Chapter 3 shows that students who have been introduced to BSL include them in their responses to the post-test questions. Thus, this is the reason why the BSL System hinges on the Articulation-cum-Reflection pedagogy which primarily aims to help students articulate their thoughts, reflect on them and at the same time invoke relevant prior knowledge within the constraints set by $B$, $S$ and $L$. 
In Table 4.1 below, we highlight some of the salient differences between the Spring Balance System and the BSL System.

<table>
<thead>
<tr>
<th>Laboratory model consists of object, spring balance, and liquid</th>
<th>Laboratory model consists of object, string, and liquid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model is dynamic</td>
<td>Model is static</td>
</tr>
<tr>
<td>Students reason about resultant force</td>
<td>Students reason about resultant force and its two components</td>
</tr>
<tr>
<td>Embedded pedagogy is ‘Provoked Reflection’</td>
<td>Embedded pedagogy is Articulation-cum-Reflection with a cognitive tool</td>
</tr>
</tbody>
</table>

Table 4.1: Differences between the Spring Balance System and the BSL System

As shown in Figure 4.1, the four other bases for the design and implementation of the BSL System are psychological and pedagogical foundations, abstracted relevant features of existing computer-based learning systems, and related human-interaction issues which have been addressed in Chapter 2. We demonstrate how some of the features for the BSL System relate to these issues in the discussion for Section 4.2.3 and Section 4.2.4.

Section 4.2.3 describes in brief the simulated laboratory model of the BSL System. Here, it displays the equilibrium of abstract BSL which are explicitly represented by arrows followed by qualitative graphs being utilised as external representational tools. The informal language employed for the definitions of BSL follows Vygotsky’s notion of the use of language as a psychological tool.

When the functionality of the system is described in Section 4.2.4, it reveals some of the underlying foundations of the system. Firstly, the system is loosely related to a microworld as it permits students to manipulate the model in such a way that is impossible in a physical laboratory setting. For example, a continuous change of an object attribute is not possible physically. Secondly, the system is considered an unintelligent non-tutoring system as it has neither a student model nor an expert domain module. Thus, students have to conduct error-discovery and error-recovery entirely on their own. The Questions Stage of the system provides no feedback while the final stage provides situational feedback. Some of the direct manipulative features which are incorporated into the design of the interface are the use of button clicks to manipulate the laboratory and equilibrium of forces models, and dragging the end points of the graphs to modify their slopes. Slide indicators on the screen to indicate the qualitative amount of change in a variable is another example to demonstrate its direct manipulative interface. The multiple-linked representation feature is exemplified by the causal links between these two models and the graphs.
In Section 4.2.4, well-defined and ill-defined problem-solving tasks in the system are mentioned very briefly. When students perform the tasks in the second stage, they are actually demonstrating Vygotsky’s notion of ‘ascend’ process of concepts whereby prior knowledge and spontaneous concepts are harnessed for predicting solutions to the problems. On the other hand, tasks in the final stage of the system exemplify the ‘descend’ process since it involves experimentation, and evaluation of hypotheses. In order to activate Piaget’s theory of equilibration, the novelty of these tasks is emphasised so that the assimilation and accommodation processes will occur to effect learning. Lastly, constructivist learning is realised when the following learning strategies are employed: discovery and exploratory learning, learning through articulation, reflection and reasoning.

4.2.3 General description of the interface

The BSL System is divided into three stages: Introduction Stage, Questions Stage, and Problem-Solving Stage. All in all, there are twenty different interfaces for students’ exploration. In this section, we only describe some essential features of these interfaces (a detailed transcript of a student’s interaction with the BSL System will be given in Chapter 5).

i. General features for the whole system

Menu Bar

Every interface has a menu bar with two items: File and Navigation (Figure 4.7a). The File submenu allows students to Save their work, Reset the objects in the interface or Quit their exploration. Navigation enables students to navigate freely within the system. The navigation structure is illustrated in Figure 4.2.

Buttons for sequential navigation

Every interface has a button for navigating to the previous page and another to the next page (Figure 4.7a).

Laboratory model

The two laboratory models depicted in Figure 4.3 are for the floating and for the sinking situations. The three objects in the laboratory model are body, an object which is incompressible; a string that is non-elastic; and liquid that is incompressible. In the model, the student has to imagine that he is holding the string up so that the system is always in a static equilibrium.
Figure 4.2: Navigation structure of the BSL System
**Figure 4.3: Laboratory models**

**Equilibrium of forces model**

In the interface, arrows represent the concretised abstract forces which exemplify Teodoro’s (1994) notion of ‘concrete-abstract’ objects. The three forces that are perpetually in static equilibrium are *Body Force* (B) which is the weight of the body, *String Force* (S) is the tension in the *string*, and *Liquid Force* (L) is the buoyant force of the *liquid*. The equilibrium of forces model is depicted in Figure 4.4. As mentioned in Chapter 2, this model exemplifies Teodoro’s (1994) notion of ‘concrete-abstract’ objects.

**Figure 4.4: The equilibrium of forces model**
Graph paper

The graph paper consists of either a one-dimensional or two-dimensional qualitative graphs shown in Figure 4.5. In the Introduction Stage, students have to observe the effects of change in BSL on their respective graphs. As for the subsequent stage in the system, students use graphs to represent their predicted solutions. In the final stage, both the given problems and results of an experiment are depicted pictorially in the form of graphs.

![One-dimensional graph](#) ![Two-dimensional graph](#)

Figure 4.5: Qualitative graphs

Record-keeping facility

The system creates a log-file containing all student’s interactions with the BSL System for analysis purposes. These files provide the following information: button clicks, time stamps for every action, variables manipulated with direction and quantitative amount of change, and the starting point and end point of each graph segment.

Features for the Introduction Stage

In this stage, the system first introduces the objects of the laboratory model to the user followed by the equilibrium of forces model together with a list of definitions phrased in simple lay terms instead of the typical formal language. As already mentioned, the rationale for using such an informal language is to facilitate easy comprehension and also to invoke experiential knowledge. The contents in Table 4.2 represent the ‘Articulation-cum-Reflection’ tool embedded in the system.

<table>
<thead>
<tr>
<th>Terms</th>
<th>Definitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body Force ((B))</td>
<td>Weight of the body</td>
</tr>
<tr>
<td>String Force ((S))</td>
<td>Force in the string which prevents the body from falling</td>
</tr>
<tr>
<td>Liquid Force ((L))</td>
<td>Force in the liquid which supports the body</td>
</tr>
</tbody>
</table>

Table 4.2: Articulation-cum-Reflection Tool

In this stage, three interfaces have been designed to introduce the B, S, and L graphs separately so as to reduce cognitive load. Students can observe the linked effects of the changes in B, S, L...
on their respective graphs. However, the details of students’ exploration are further described in Section 4.2.4.

iii. Features for the Questions Stage
This second stage of the BSL System consists of both floating as well as sinking scenarios. The causal and non-causal factors of buoyant force are incorporated in the design of the ill-defined problem-solving situations. One-dimensional and two-dimensional qualitative graphs are employed to represent students’ predicted solutions. The former allows students to concurrently compare the BSL in several situations while the latter enables students to reason about the causal relationships between a change in a variable and BSL.

iv. Features for the Problem-Solving Stage
Creation of problems
The problems are represented by qualitative two-dimensional graphs. The initial states of the problem are given while the students can create the end states. BSL graphs are created when the initial positions of the BSL are joined to their corresponding end positions.

Variables Menu
The Variables Menu comprises five variables that can be manipulated by students: Density of Body, Density of Liquid, Width of Body, Height of Body, and Immersed Volume of Body. The first four variables can either be increased or decreased with a qualitative amount. The last variable can only be decreased because the given initial positions for B, S and L in the problem are for a fully immersed body (Figure 4.15a).

Creation of solution to the problems
Students create a solution to a problem by manipulating one or more variables. Indicators provided in the interface help students determine whether their solutions are correct. Details of the process are further described in the subsequent section.

4.2.4 Functionality of the BSL System
This section describes student-system interactions for every stage of the system.

Stage 1: Introduction Stage
As mentioned earlier, this stage aims to introduce the student to the objects of the simulated laboratory model and the cognitive tool in the form of simple object-related definitions for BSL. In addition, it helps students to map the model to the graph, and observe the effects of the change
in the BSL forces on their corresponding graphs. The overall sequence of student-system interactions is depicted in Figure 4.6.

![Diagram of student-system interactions]

**Figure 4.6: Sequence of students’ interactions in the Introduction Stage**

The tasks in Pages 3, 4 and 5 are exploratory in nature. We shall first describe the interactions for manipulation of B in Page 3. The model for this page is a suspended body in air (Figure 4.7a). When the button *Animate Arrow* is pressed, a replica of *Arrow B* in the model moves to the graph and stops when its tail touches the origin of a two-dimensional graph. Immediately, an *Ellipse B* appears at the head of *Arrow B* followed by the disappearance of replica of *Arrow B*. *Ellipse B* can be seen in the *Graph Paper* of Figure 4.7b. The purpose of this animation is to help...
students establish the fact that the magnitude of Arrow $B$ in the model equals the distance between the centre of Ellipse $B$ and the origin of the graph.

![Image](image1)

Note: Contents of call-outs are either labels or magnified buttons

Figure 4.7: Manipulation of $B$

The procedure for manipulating $B$ begins with the selection of a qualitative amount of change for $B$. This is made possible by sliding a red indicator along a line with its two ends labelled as *less* or *more* (Figure 4.7c). This is followed by clicking on the button *Increase* or *Decrease* (Figure 4.7c). When any of these buttons is clicked, concurrently, the Arrow $B$ changes in magnitude and so does the position of Ellipse $B$. The $B$ graph generated is displayed in Figure 4.7c.

The model for Page 4 is similar to that in Page 3 except that $S$ is labelled. The same procedures for $B$ apply to this page except that $S$ has to be manipulated indirectly through $B$ (Figures 4.8a, b, c). This is to enable students to perceive $S$ as a dependent variable and view the effects of the change in $B$ on $S$, as well as their respective graphs. The model for *Page 5* is the equilibrium of forces model. There is not much change to students’ exploration in this stage except that students can manipulate $B$ or $L$, observe the changes in its counterparts if there is any and also the corresponding changes in the BSL graphs (Figure 4.9).
Stage 2: Questions Stage

This stage comprises ill-defined problems with given initial positions of Ellipses BSL. Students are required to predict the end positions of the ellipses based on the causal effect of a variable on BSL and represent their solutions in either a one-dimensional or two-dimensional graphs. The tasks with their respective types of graphs and the correct relationships to be discovered by students are tabulated in Table 4.3.
### Chapter 4 The BSL System

#### Table 4.3: Sinking and floating tasks of the Questions Stage

<table>
<thead>
<tr>
<th>Type of situation</th>
<th>Task</th>
<th>Variable</th>
<th>Constant attributes</th>
<th>Type of graph</th>
<th>Relationship with BSL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sinking</strong></td>
<td>Task 1</td>
<td>Depth of submergence</td>
<td>$V_o$, $\rho_o$, $\rho_l$</td>
<td>2-D</td>
<td>B-non-causal S-non-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 2</td>
<td>State</td>
<td>$V_o$, $\rho_o$, $\rho_l$</td>
<td>1-D</td>
<td>B-causal S-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 2.1</td>
<td>Solid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 2.2</td>
<td>Hollow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 3</td>
<td>Condition</td>
<td>$V_o$, $\rho_o$, $\rho_l$</td>
<td>1-D</td>
<td>B-non-causal S-non-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 3.1</td>
<td>Vertical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 3.2</td>
<td>Horizontal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 3.3</td>
<td>Slanted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 4</td>
<td>Density of Body</td>
<td>$V_o$, $\rho_l$</td>
<td>2-D</td>
<td>B-causal S-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 5</td>
<td>Volume of Body</td>
<td>$V_o$, $\rho_o$, $\rho_l$, $H$, $B$, $\rho_o$, $\rho_l$</td>
<td>2-D</td>
<td>B-causal S-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 5.1</td>
<td>Width of Body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 5.2</td>
<td>Height of Body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 6</td>
<td>Volume of Immersion</td>
<td>$V_o$, $\rho_o$, $\rho_l$</td>
<td>2-D</td>
<td>B-non-causal S-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 7</td>
<td>Shape</td>
<td>$V_o^<em>$, $\rho_o^</em>$, $\rho_l$</td>
<td>1-D</td>
<td>B-non-causal S-non-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 7.1</td>
<td>Cone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 7.2</td>
<td>Sphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 7.3</td>
<td>Slanted Cylinder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 8</td>
<td>Volume of Liquid Column</td>
<td>$V_o$, $\rho_o$, $\rho_l$</td>
<td>1-D</td>
<td>B-non-causal S-non-causal L-non-causal</td>
</tr>
<tr>
<td></td>
<td>Task 8.1</td>
<td>Small Liquid Column</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 8.2</td>
<td>Height of Liquid Column</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 8.3</td>
<td>Width of Liquid Column</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task 9</td>
<td>Density of Liquid</td>
<td>$V_o$, $\rho_l$</td>
<td>2-D</td>
<td>B-non-causal S-causal L-causal</td>
</tr>
<tr>
<td><strong>Floating</strong></td>
<td>Task F1</td>
<td>BSL</td>
<td>None</td>
<td>1-D</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Task F2</td>
<td>Size</td>
<td>$\rho_o$, $\rho_l$</td>
<td>1-D</td>
<td>B-causal S-non-causal L-causal</td>
</tr>
<tr>
<td></td>
<td>Task F2.1</td>
<td>Small Block</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task F2.2</td>
<td>Big Block</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task F3</td>
<td>Density of Body</td>
<td>$V_o$, $\rho_l$</td>
<td>2-D</td>
<td>B-causal S-non-causal L-causal</td>
</tr>
<tr>
<td></td>
<td>Task F4</td>
<td>Density of Liquid</td>
<td>$V_o$, $\rho_o$</td>
<td>2-D</td>
<td>B-causal S-non-causal L-causal</td>
</tr>
<tr>
<td></td>
<td>Task F5</td>
<td>Volume of Body</td>
<td>$H$, $B$, $\rho_o$, $W$, $B$, $\rho_l$</td>
<td>2-D</td>
<td>B-causal S-non-causal L-causal</td>
</tr>
<tr>
<td></td>
<td>Task F5.1</td>
<td>Width of Body</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Task F5.2</td>
<td>Height of Body</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The column for ‘Relationship with BSL’ contains correct relationships to be discovered by students. Constant attributes with * are attributes made explicit through text displayed on the screen. Constant attributes without * are implicit attributes which students should be aware of. The term ‘Condition’ means orientation.

**Key:**
- $V_o$ - volume of body
- $\rho_o$ - density of body
- $\rho_l$ - density of liquid
- $W$ - width of body
- $H$ - height of body
- $B$ - breadth of body
- 1-D - One-dimensional
- 2-D - Two-dimensional

Table 4.3: Sinking and floating tasks of the Questions Stage
The sequence of students’ interactions in a sinking two-dimensional problem of Stage 2 in the system is illustrated in Figure 4.10.

![Diagram](image)

**Figure 4.10: Student’s sequence of actions for sinking situations with 2-D graphs**

At the outset of the exploration, the model displayed on the screen is the equilibrium of forces model for the sinking scenario and a two-dimensional graph with the *Start Ellipses BSL* (Figure 4.11a). Students manipulate an attribute of the body or liquid by clicking on the button *Increase* or *Decrease* with the *Arrows BSL* disappearing from the screen (Figure 4.11b and Figure 4.12b). However, the model changes accordingly. As the student explores the system, he articulates and reflects on the causal effect of the manipulation on BSL. When he predicts the causal relationships between the variables and BSL, he has to justify his prediction.

![Images](image)

**Figure 4.11: Run an experiment without feedback**

Subsequently, he creates graphs to represent his solution and the predicted two-dimensional graphical solutions are illustrated in Figure 4.12.

The procedures for creating two-dimensional graphical solutions are as follows:

i. Click on *Ellipses BSL* in the box to create *End Ellipses BSL* (Figure 4.12a)
ii. By default the End Ellipses BSL appear on x-axis (Figure 4.12a)

iii. BSL graphs are straight lines joining the Start and corresponding End Ellipses (Figure 4.12a)

iv. Student drags End Ellipses BSL, one at a time, to modify slopes of BSL graphs (Figure 4.12b)

v. If BSL graphs remain constant, student can right button clicking on a Start ellipse followed by its corresponding End Ellipse and lastly, click on button Align Ellipses (Figure 4.12b)

A student’s sequence of actions for sinking problems with one-dimensional graphs is similar to that depicted in Figure 4.10. Here, each problem has more than one situation which can be invoked through button clicks. Students are required to qualitatively compare and contrast the magnitude of BSL for the involving situations, and subsequently, represent their solutions in one-dimensional graphical forms which are depicted in Figure 4.13. The procedures for creating one-dimensional graphs are as follows:

i. Click on Ellipses BSL in the box to create new Ellipses BSL (Figure 4.13c)

ii. By default the new Ellipses BSL appear on origin (Figure 4.13c)

iii. Student drags and drops new Ellipses BSL, one at a time, along the y-axis (Figure 4.13d)

iv. Student can align the co-ordinate y of an ellipse in the second graph with another ellipse in the first graph by right button clicking on both the ellipses followed by clicking on button Align Ellipses (Figure 4.13d)

For the floating situation, the functionality of the system is similar to that of the sinking situations except that the model on display is a floating equilibrium of forces model without Arrow S since S equals zero when a body is floating.
Stage 3: Problem-Solving Stage

Figure 4.14 displays a sequence of student-system interactions for solving problems. The description for the interactions is divided into the following sub-headings: creation of real target graphs, manipulation of variables, evaluation of hypotheses and reset of manipulation.

The interface consists of the equilibrium of forces model for sinking. The well-defined problems in this section are represented by graphs. The initial states of the problems are indicated by the Start Ellipses BSL (Figure 4.15a) while the final states are represented by the End Ellipses BSL (Figure 4.15c). BSL graphs are lines connecting the Start Ellipses BSL to their corresponding End Ellipses BSL (Figure 4.15c). The two types of problems that can be created here are real problems (Figure 4.15d) and unreal problems with S being negative (Figure 4.16). The reason for considering only unreal problems with a negative S will be given later in this section.
Chapter 4 The BSL System

Figure 4.14: Sequence of student-system interactions for real problem-solving tasks

Creation of target graphs
Clicking any two of the three ellipses in a box creates two End Ellipses BSL (Figure 4.15b, c). Immediately, the third end ellipse automatically appears followed by BSL graphs which join the Start Ellipses BSL to their corresponding End Ellipses BSL (Figure 4.15c). Any of the two created End Ellipses can be dragged so as to change the slope of its graph and also effecting a simultaneous change in the position of the third end ellipse. If S is positive then the target graphs are real (Figure 4.15d). Conversely, when S is negative then the target graphs are unreal and this can be seen in Figure 4.16. In order to change an unreal situation to a real one, the button Unreal to Real Graphs is clicked to change an unreal situation to a real one (Figure 4.16a). Here we call them modified real target graphs. As seen in Figure 4.16b, each modified real target graph consists of two segments with the first part being a sinking situation while the second is for a floating one (Figure 4.16b). Such a target graph allows students to observe a transition from a sinking situation to a floating one. The minimum values allowed for B and L in the target graphs are zero.
Chapter 4 The BSL System

Figure 4.15: Creation of a problem with a real situation (S>0)

- a. Screen display before the creation of a problem
- b. Screen display after Ellipse L in the box is clicked
- c. After the second ellipse (B) in the box is clicked, BSL graphs appear
- d. Any two of the End Ellipses (B or L) can be dragged and dropped to change the slopes of graphs

Figure 4.16: Creation of unreal and modified real target graphs

- a. Creation of a problem with an unreal situation (S<0)
- b. Modified real target graphs are created after clicking the button Unreal to Real Graphs

Ellipses BSL in box
Start Ellipse L
Start Ellipse S
Start Ellipse B

Unreal to Real Graphs
S Graph

Sinking situation
Floating situation
Display of manipulation and experimental tools

When the button Variables Menu is clicked it invokes the following objects in the interface: viewer for Variables Menu, BSL Pointers, button Press Down to Draw Graphs, button Reset manipulation, and button Reset all. These objects can be seen in Figure 4.17.

Manipulation of variables

It is imperative that students predict and justify solutions to the problems before they are allowed to manipulate the following variables: Density of Body, Density of Liquid, Width of Body, Height of Body, and Immersed Volume (only for sinking situations). The procedures for manipulating the variables are listed below:

i. Slide the indicator of a variable along the scale (Figure 4.18). Its position on the scale determines the qualitative amount of change. As the indicator moves, the heading of the BSL pointers changes accordingly (Figure 4.19a)

ii. Manipulate one or more variables until the three BSL pointers coincide with their corresponding graphs concurrently (Figure 4.19b). For the modified real target graphs, a solution is considered found when the BSL pointers coincide concurrently with the sinking segment of the modified real target graphs (Figure 4.20). In order to confirm that the solution is correct, students run the experiment.
a. When a variable is manipulated (by sliding an indicator), the heading of the relevant pointers change accordingly

b. One or more variables are manipulated so that the BSL pointers coincide with their respective target graphs

Figure 4.18: Manipulation Tool

Figure 4.19: Problem-solving process for real target graphs

Figure 4.20: Solution for modified real target graphs

Figure 4.21: Generated matched graphs (in white)
Run and observe experiment

In order to run the experiment, students have to click on the button Press Down to Draw Graphs. As this button is pressed, the model and Arrows BSL change based on students’ manipulation. Concurrently, the situational feedback as represented by matched graphs is automatically generated. Figure 4.22 displays an example of such generated matched graphs.

Figure 4.22 Experiment run for modified real target graphs (with sinking and floating situations)

When the experiment is run in a modified real problem, it is quite similar to that for a real problem except that the model will change until a critical point when it switches from a sinking situation (Figure 4.22a) to a floating one (Figure 4.22b). When the body floats, Arrow S disappears (because S=0); Laboratory and Equilibrium of Forces models, and graphs change accordingly. Here, students have to infer the relationships between the variables manipulated and BSL for the floating scenario.

Evaluation of solution

Students evaluate the correctness of their solutions by comparing the target and matched graphs (Figure 4.23). If both coincide or the general shapes are similar then the solutions are considered correct.

Reset manipulation

The Reset manipulation facility is invoked when students want to predict, run and evaluate an alternative solution. When the button Reset manipulation (Figure 4.23) is clicked the following events will occur:

i. Reset model
ii. Reset Arrows BSL
iii. Reset BSL pointers
iv. Reset indicators of Variables Menu
v. Clear matched graphs

**Reset all**

This facility is utilised when students progress to a new problem. The clicking of the button *Reset All* (Figure 4.23) will trigger off the following series of events:

i. Reset all manipulation

ii. Delete *End Ellipses BSL*

iii. Delete *BSL graphs*

![Figure 4.23: Comparison of real target and matched graphs](image)

### 4.2.5 Conclusion

Both well-defined and ill-defined problems in the system are represented by graphs. The incorporation of familiar yet novel situations aims to invoke both the reflection process as well as student’s prior knowledge. In Stage 2 of the system, the prediction-reflection strategy is greatly emphasised while the pivotal strategy employed for the third stage is the predict-test-reflect strategy. This means that no feedback is provided in the *Questions Stage* but situational feedback is provided in the *Problem-solving Stage* instead. When using modified real problems, students are given the opportunity to observe a transition from a sinking situation to a floating one and thus be made aware of the causes that trigger off the switch of scenarios.
4.3 Formative Evaluation

4.3.1 Aims
Primarily, the aim of this phase is to evaluate the BSL system, its supplementary materials and experimental procedures for revision purposes.

4.3.2 Expert appraisal
Two HCI experts evaluated the interface for the Problem-Solving Stage. The outcome of this expert appraisal was refinement of the screen-displayed instructions, help menu, and Variables Menu. It was also suggested that a worksheet be designed to reduce students’ memory load. This worksheet is described in Chapter 5.

4.3.3 Try-out session
The whole BSL System, experimental procedures, and the worksheet were pilot tested on two PhD research students who worked on it individually with the experimenter as the facilitator. The main aim of this trial session was to uncover problems that students might face when exploring the system. The outcome of this session showed that there is no technical problem with the system. Neither was there any problem with the worksheet nor experimental procedures. Subjects merely requested the clarification of the word, density and this is the reason why a glossary of terms was created.

4.3.4 Summary
The results of the formative evaluation formed a basis for revising the embedded instructions of the BSL System, its help menu and also the Variables Menu. The idea of designing a supplementary worksheet and a glossary of terms is another consequence of the formative evaluation.

4.4 Conclusions
The BSL System provides a problem-solving environment that promotes active construction of new knowledge based on prior knowledge. Its embedded cognitive tool aims to help students articulate their thoughts, facilitate reflection and reasoning during the problem-solving processes. The learning strategies implemented with the system are predict-reflect or predict-test-reflect. The conduct of the experimental study using the BSL System will be described in Chapter 5. One of main focuses of this research is to analyse students’ search space between the initial and final states of the problems and the results of the analysis are presented in Chapters 6, 7 and 8 of this thesis.