

# **A Methodology to Study Students' Explanatory Models for Buoyant Force: Spiraled Exploratory Inquiry and Hypotheses Testing**

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## **Abstract**

This paper reports a novel experimental design that was developed to carry out an inquiry about explanatory models that university students have about buoyant force. This experimental design involved two stages: a spiraled exploratory inquiry and the testing of the working hypothesis. The first stage consisted of a series of steps that are successive approximations towards the identification of the students' models. These steps are: a preliminary design of a potentially adequate inquiry instrument, the collection and analysis of data (students' answers), and the ordering of the given explanations on the base of "answer categories" that were defined and coded. These steps allow the detection of characteristic configurations given by the simultaneous presence of certain categories. These configurations were named "category groupings" and were taken as indicators of the existence of explanatory models. With these results, the preliminary inquiry instrument was improved in order to refine the categories that were detected in the first step. Then new data collection was carried out three times, following the same set of steps. The hypothesis testing stage was planned taking into account these results. This research made use of qualitative and quantitative techniques. In all cases, the instruments' validity was checked. As a result of this research, a set of explanatory models about buoyant force that students study when dealing with bodies submerged in liquids, was proposed. The degree to which these models are shared by students was quantified. A selective activation of different explanatory models was identified, depending on the problem situation at hand.

## **Introduction**

This paper reports the experimental design adopted for the development of an inquiry of university students' explanatory models for buoyant forces. The working hypotheses were:

H1: Faced with problem-solving situations that involve submerged bodies, students use explanatory models about buoyant force.

H2: There are groups of students who share the same explanatory model.

H3: Students may have different coexisting explanatory models and use one or another depending on the context of the problem situation at hand.

An experimental design for the detection of students' explanatory models - taking into account the point of view we proposed at the

beginning of this inquiry - was not found within the bibliographic search (Cohen & Manion, 1996; Creswell, 1998). Previous works had already described some naive conceptions that students have about this topic (Fernandez, Jardón, Laura & Utges, 1993; Flores Camacho & Gallegos Casares, 1998). The purpose of this work was to detect the variables that students considered relevant to explain the buoyant force and the relationships they established between those variables. Because different students used different intuitive conceptions, we expected that different students adopted different variables and relationships to explain buoyant force. In a first stage, we designed an exploratory inquiry which allowed us to detect explanatory models. In a second stage the hypotheses testing was carried out on the basis of the explanatory models found.

## **Methods**

The experimental design was planned in steps: “spiraled exploratory inquiry” and “hypotheses testing”. A combination of qualitative and quantitative techniques was used during the research. During both steps statistical analysis were made whenever they were considered relevant (for example, to define the selected population of students needed to testing the three hypotheses put forward) (Siegel, S., 1970).

### ***Spiraled Exploratory Inquiry***

During the spiraled exploratory inquiry successive approaches were made, through the following activities:

- Design of research instruments potentially adequate for the inquiry.
- Data collection and report of students’ answers to questions related to buoyant forces.
- Classification of the elicited explanations, defining and coding “answers categories” according to answers based on any characteristic considered relevant by students (For example, “Buoyant force depends on the amount of liquid in the container”, codified C5).
- Analysis of the way in which students made use of different categories, and detecting patterns, named “category groupings” (For example, some students only used categories codified A1 and C3). These category groupings were considered as possible indicators of explanatory models.
- Reformulation of tools and new data collection.
- New revision of the relevancy of the categorizations and of their groupings depending on the new information.

This whole process involved the elaboration of three questionnaires and a semi-structured protocol interview.

Questionnaires – for individual and written answers - and interviews were used for collecting data. Questionnaires make possible to obtain answers from large groups of students. Interviews provide a deeper insight into students’ concepts and forms of reasoning. Incidental

samplings were selected for the questionnaires. Reputed cases were selected for the interviews.

An incidental sample (Sirvent, 1997) does not have the characteristics of statistical sampling. In this research, the groups were made up of students who, besides taking a certain university course during a certain academic year, attended classes on the day in which the questionnaire was administered. Individuals chosen by their reputation are referred to as reputed cases (Sirvent, 1997). In this research, they were students with high academic performance.

In every case, both for questionnaires and for interview protocols, the study of instrument validity was conducted through their consideration by external judges and the development of pilot experiences (answers elicited from small groups of students). This made possible to control the clarity of the answers and their relevance for the research objectives. In each case, definitive versions were written down following the modifications resulting from both instances.

For the control of instrument reliability, they included more than one question pointing to a same aspect.

Questionnaire 1 was administered to Group 1 (students from different degree programs in UNSa -National University of Salta, Argentina-). The group included two sub-groups with different characteristics:

- Group "pre": Students who had not had formal university instruction on the subject "buoyant force" (freshmen), N = 78.
- Group "post": Students who had already studied the subject "buoyant force" (students taking the Physics II course and who had studied Hydrostatics in the previous semester), N = 25.

Questionnaire 2 was administered to a team of students labeled Group 2, made up of five groups of students from different university courses, all of them with formal instruction on Hydrostatics:

- Group Ex: Chemistry students (Licentiate and Teacher Training courses), UNSa. (N=12).
- Group Geo: Geology students, UNSa. (N=11).
- Group Nat: Agronomical Engineering students, UNSa. (N=26).
- Group Ing1: Engineering students (Civil, Chemical and Industrial), UNSa. (N=13).
- Group Ing2: Civil Engineering students, UNT (National University of Tucumán, Argentina). (N=18).

Semi-structured interviews were administered to a small number of students with the aim of obtaining more complete verbal explanations to be analyzed. The protocol of a semi-structured interview and some simple experimental devices (necessary for the implementation of the interviews) were designed. During the interview students were faced with concrete experimental situations related to submerged bodies, and they were required to make predictions and give explanations on the behavior of the bodies involved. The interviews were given to students selected as

reputed cases, all of them having formal instruction on Hydrostatics and high academic performance (all of them from UNSa).

The predictions and the explanations elicited showed some severe misunderstandings, even though they came from students with a high academic performance. These misunderstandings were mainly related to the volume displaced by the body, to the distinction between weight and apparent weight, and to the variables related to the buoyant force. After a reflective analysis of the behavior of simple experimental systems, students who initially gave conceptually incorrect answers were able to clarify the concepts involved.

Questionnaire 3 was designed to develop the Pilot Experience of Hypotheses Testing. It was aimed both at inquiring about explanatory models on buoyant force already identified, and at exploring the existence of other possible students' explanatory models. In this stage, a decision had been taken to restrict the administration of the questionnaire to students from UNSa, as a result of a statistical analysis. Thus, questionnaire 3 was administered to a group of students (who had already studied the subject "buoyant force") referred to as Group 3 (N=103).

When the previous stages were finished, we had a preliminary set of categories and explanatory models proposed.

### ***Hypotheses testing***

The stage of Hypotheses Testing was planned on the basis of the results obtained from the Pilot Experience. A new tool was designed. Questionnaire 4 was administered to Group 4, made up of 97 students from different degree programs in UNSa, who had already studied the topic Hydrostatics. A statistical analysis showed that no meaningful differences could be detected between Group 4 and Group 3. In another paper (Alurralde & Salinas, 2006) a discussion is presented of the results obtained during the development of the research.

### **Results**

Table 1 resumes the results in relation to the categories of answers. The final listing of answer categories which were used for the hypotheses testing is shown.

A1	The buoyant force depends on the volume of liquid displaced.
B1	The buoyant force depends on the weight/mass of the body.
B2	The buoyant force depends on the density of the body.
B3	The buoyant force depends on the volume of the body.
C1	The buoyant force increases when depth increases.
C2	The buoyant force depends on pressure.
C3	The buoyant force depends on the density of the liquid.
C4	Student does not discriminate buoyant force/pressure.
D	The buoyant force depends on the horizontal surface of body-liquid contact.
E1	In the presence of other forces student does not know how to explain the buoyant force.
E2	The buoyant force does not act or is less when the body is in equilibrium.
E3	The buoyant force depends on the connections.
G1	The buoyant force is greater if the body is higher (degrees of floatability).
NA	Non-usable answers.

Table 1. Answer categories

From the final categories listing shown in Table 1, students' arguments were revised. Through this analysis, explanatory models shown in Table 2 were proposed.

Scientific Model: comprised by answers consistent with the scientifically accepted model. Those students who seem to committed to Scientific Model exclusively use answer categories A1 and C3.
Model 1: The variables considered relevant for buoyant force are those linked exclusively to the submerged body (mass, weight, density, volume). Those students who seem to adhere to Model 1 use answer categories B, but do not use answer categories C (except for C3 which might be used on certain occasions).
Model 2: The variables considered relevant for buoyant force are linked only to the fluid (pressure, depth). The students who seem to adhere to Model 2 use answer categories C, but do not use answer categories B.
Model 3: The higher the body is in the liquid, the stronger the buoyant force is (at lower depth). This model seems to define a "flotation degree" for bodies, associating a stronger buoyant force to bodies that are closer to the surface.

Table 2. Explanatory models proposed

The set of explanatory models described above was proposed as an interpretation of the category groupings present in students' answers. Groups were found of students who shared these grouping and that, consequently, seemed to share the adhesion to the associated models.

From the analysis of students' answers that showed category groupings which didn't seem to fit in any of the defined models, new evidences appeared to show that, in physically equivalent situations, students gave different explanations in terms of some particular condition present in the problematic situation put forward. These explanations were characterized as category groupings Type QA (Pairs question-answer), as shown in Table 3.

## Conclusion

The working methodology of this inquiry was not a conventional one. Some naive students' conceptions were known (Alurralde & Salinas, 1999), and they were similar to the ones detected by other authors (Fernández et al. 1993; Flores Camacho & Gallegos Casares, 1998).

Type	Alternative explanations	
QA	For bodies partially submerged, they adhere to Model 1	For bodies completely submerged, they adhere to Model 2
QA1	In the absence of connections, they adhere to Model 2.	In the presence of connections, the buoyant force depends on the connections.
QA2	In the absence of connections, they adhere to the model accepted scientifically	In the presence of connections, the buoyant force depends on the connections.

*Table 3. Students' Q-A Type responses*

Following the orientation of those results and of teaching experience on the subject, an inquiry was designed. It did not look explicitly for predetermined conceptions, but it put forward problematic situations which made possible the detection of the variables which students considered relevant for buoyant force. Then, also in an open way, without limiting the inquiry to the finding of predetermined particular structures, characteristic answer grouping were searched for. They were taken as indicators and through them it was possible to propose explanatory models as an interpretation of students' answers. This process was developed in successive steps, and the results obtained from data collection were revised in several occasions. Each new category of answer or each new characteristic grouping demanded a new revision of questionnaires and transcriptions of interviews in the light of the new information. That is the reason why the stage previous to the hypotheses testing has been characterized a "spiraled exploratory inquiry".

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