Impact of Embodied Interaction on Learning Processes: Design and Analysis of an Educational Application Based on Physical Activity

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ABSTRACT
There is a growing interest in learning studies about the use of interaction models that involve sensorimotor activities and affordances within an educational experience. This paper explores how concrete experiences, in this case an educational application designed for an Interactive Slide, can make concepts of buoyancy and Archimedes' principle understandable to children. We hypothesized that the relationship between kinesthetic experience and the Interactive Slide's affordances would improve learning. To test this hypothesis we have defined two principal experimental conditions, using the same application on the Interactive Slide and on a desktop computer, and compared the results from a sample of 331 children through pre and post-tests. Our results show modest but noticeable improvements in test scores from children assigned to the Interactive Slide condition. The results of this study highlight the opportunities of the Interactive Slide as a learning environment to foster the processes of building abstract concepts. However, additional exploration is necessary to improve the design strategies for new applications and refine the assessment methodology.

Categories and Subject Descriptors
H.5.1 **[Information interfaces and presentation]**: Multimedia Information Systems - Artificial, augmented, and virtual realities; H.5.2 **[User Interfaces]** (D.2.2, H.1.2, I.3.6) Ergonomics. K.3 **[Computers and Education]:** Computer Uses in Education

General Terms
Design, Experimentation, Human Factors, Measurement, Performance

Keywords
Full-body Interaction, Children, Learning, Education, Playgrounds, Physical Activity, Abstract Concepts, Interaction Design, Exertion Interfaces, Learning Environments, Kinesthetic Learning

1. INTRODUCTION
Information and communication technologies are rapidly changing the way we experience the world. There is a clear discontinuity between previous generations and the "digitally grown" generation, as Prensky describes [31], which is reflected in the way of thinking, learning, processing information and management of leisure.

This renewed social context is a challenge for the educational community. It requires a recasting of teaching methods and educational models. These models must offer effective learning strategies in a digital era [33], must encourage learners to take an active role in their own education, and must provide useful strategies for management of information. The models must also allow learners to transform information into knowledge through research, selection, assimilation and re-elaboration.

These challenges led our group to outline our research questions in relationship to technology in education and the implications and impact of using a particular interface in the learning process.

In the past, the academic community has focused on the test and research of new patterns of interaction to increase the rank of human capacities involved in interactive experiences and to improve the development of certain practices [12]. Within this field we are particularly interested in the inclusion of the role of physical artifacts and embodiment in the interactive learning experience, to investigate the Interactive Slide as an exertion interface that supports the development of educational applications based on active learning principles.

This paper first provides references to the current paradigms related to the relationship between embodied cognition, situated activity and knowledge construction through the description of related works and models. It then provides a description of the Interactive Slide as a learning platform, and an overview of the design strategies used to build an educational application ——in which the kinesthetic experience provided by the Interactive Slide is used— to foster the learning process. The paper then describes the comparison of the educational impact of the application used in the Interactive Slide and in a traditional interface (i.e. a desktop computer), this comparison was used to assess whether the difference in the model of interaction could represent a significant gain in the learning process. In the last section we discuss the results, outlining their limitations and suggesting paths for future work.

2. STATE OF THE ART

2.1 Context, Situated Activity and Cognition

For the purposes of this research, it is of particular interest to consider the learning frameworks that deal with models of cognition that include embodiment and embeddedness, and are based on the relationship between the role of physical artifacts, experience, activity and learning.

Piaget offers an interesting perspective regarding the relationship between activity and learning: he defines the acquisition of knowledge as a dynamic process generated by the interaction between the learner and her social and physical environment, where "understanding is a situated process, function of the content, the context, the activity and the goal of the learner" [16]. The constructivist model is based on the idea that people construct their knowledge from active experience and learning arises from the construction of cognitive structures acquired through action in the world.

This idea is shared by Activity Theory which states that "conscious learning emerges from activity" [19] and places a strong emphasis on the role of the environment and physical artifacts in the construction of cognitive processes. According to Vygotsky, physical artifacts play the role of mediators of human thought [39] and shape the type of activity and experience through interaction with the subject [5, 25, 27].

These models are consistent with findings in cognitive science that analyze the relations between the role of activity, context and bodily experience in the development of cognitive features.

Several authors propose cognitive models aimed at integrating mind, body and world into sense-making and knowledge construction processes.

Starting with the assumption that physical artifacts shape the nature of activities and experiences, Varela (in [11]), expands this definition by describing the process of "sense-making" as an activity-based experience in the world. Wilson also stresses this by stating that "The forces that drive cognitive activity […] are distributed across the individual and the situation as they interact" [40] and materialize themselves in the participatory process of the action enacted in the context.

This approach is consistent with the theoretical frameworks based in the role of bodily experience in the development of cognitive processes. The concept of embodied cognition arises from the idea that thoughts, concepts and mental models are influenced and determined by the role of the physical states, bodily structures [2,41] and experiential opportunities that are feasible by being located in a specific context. It suggests the hypothesis that not only do cognitive processes linked to mastering sensorimotor contingencies [15] meet their origin in embodied experiences, but "also higher-level cognitive skills - as mental imagery, working memory, implicit memory, reasoning and problem solving, may arise from sensorimotor functions" [40].

Bodily experience, through its actions in a situated context, became therefore the tool at the basis of the processes of construction of meaning, by allowing the transfer from concrete experience to explicit knowledge [6].

Interesting examples can be found in Glenberg's research [14] that suggests that meaning could arise from affordance and can be considered as a function of how the body can interact with a specific object. This hypothesis is strengthened by the finding of Lakoff and Gallese [13], who argue that the formation of linguistic concepts meets its bases in the sensorimotor system.

Within this framework, it seems logical to consider the importance of the relationship between concrete experience and abstract concepts and to infer that there is a correlation between the wealth of situated activity and the wealth of mental models; e.g. a study conducted by Goldin-Meadow shows a correlation between the gestural activity of the parents and richness of vocabulary in children [18].

These examples suggest the importance of environmental stimuli and physical artifacts in the construction of sensorimotor experience and how such kind of experience is crucial in the development and conformation of our cognitive processes.

This research, applied in the field of digital technologies, emphasizes the need to rethink technology in a post-Cartesian approach, stressing the environmental stimulation and the sensorimotor and activity-based experience, to foster a diverse and differentiated development of our cognitive abilities.

2.2 Related works

Several Learning Environments have been developed to include the use of physical activity and material context as a means to improve the effectiveness of the educational process and foster learning. Some of them arise from the idea that "gesture and body language do not only reveal aspects of the learning processes but also can help to learn in a special way" [23], specifically through the generation of contexts able to engage mind and body in exploring concepts by acting upon them [4].

There are different types of approaches to using and analyzing physical activity in educational contexts. A first example of this trend comes from studies by Price and Rogers with the use of digitally augmented physical spaces within the projects Chromarium, Hunting the Snark and the Ambient Wood. These projects analyze how physicality can promote active learning and focus around the type of exploratory activities and the level of involvement of participants. These studies show that the use of physical activity in a Learning Environment promotes involvement and activeness, increases awareness of one's own actions, enhances creativity and encourages reflection [32, 35].

In the design and analysis of the Polymechanon, Kynigos et al, focused on the role of the body as a mean to express understanding and thinking processes. The authors study how the body can help to learn and, at the same time, is able to express the understanding of concepts through gestures, movements and actions [23]. The unit of analysis is constituted by the concept of "action centered understanding", meaning that this understanding lies in the action and is expressed by the intelligent connection between movements, gestures, communication and concepts embedded in the game. From this analysis, the authors show the significant role of kinesthetic experience in understanding mathematical and scientific concepts.

These examples show an approach to the relationship between understanding and action that is focused on a kind of knowledge that is not declarative [29] but corresponds to a "know-how" which is directly embedded in performing an intelligent action.

Action centered understanding is useful as a starting point to look at how embodied understanding could evolve into a declarative and explicit form of knowledge. Manches et al., in their analysis of the role of physical manipulation, states that the development of ideas may be grounded in children's perceptual experience, and that learning could represent the ability to map from concrete experience to abstract representations [26]. Therefore while designing a virtual environment that involves physical activity, it is important to stress a strong relationship between action and cognition so it leads to the mapping of experience to knowledge.

Some examples related to the use of the interactive experience as a tool to communicate meaning and abstract concepts come from the interactive installations Water Games and Connections by Parés and Carreras [30, 7]. Both installations are based on the idea of using user interaction as the tool to make children reflect and think about abstract concepts embedded in the interaction model. In Water Games users interact with the system by forming and spinning a ring: in this way the allegory produced by their behavior allows them to experience and reflect about concepts of peace, sustainability and respect to cultural diversity [30]. In Connections, children have to form human networks by connecting different nodes: the concept of science as a networked structure is embodied by the users and therefore experienced through an analogous interaction scheme provided by the installation [7].

2.3 The Interactive Slide Platform

The overview of Learning Environments based on physical activity outlines the importance of using interfaces capable of offering meaningful sensorimotor experiences to facilitate the acquisition of knowledge in the transfer from concrete experience to abstract concepts. In our study we have focused the design strategy on the analysis of the specific features of the Interactive Slide, to take advantage of its affordances and interaction potential to build a meaningful mapping between user experience and educational content.

Figure 1: Close view of the Interactive Slide with the projection of the virtual environment on the sliding surface.

The Interactive Slide is a large inflatable slide augmented with interactive technology: it has a sliding surface 4 meters wide and 3 meters tall, which functions as a projection screen. A computer vision system detects the user's movements and actions: in this way it augments a well-known play structure and allows children to play an interactive experience on the sliding surface [38] (Figure 1).

The Slide, by incorporating full-body interaction, social environment creation and game dynamics, offers a highly interesting context to create learning environments.

Several studies show that playing creates an active involvement of the player [34] and produces a state of intrinsic motivation that can completely immerse the player [17]. These features are strengthened by the relationship between play and physical activity. Mueller stresses that exertion interfaces increase the level of engagement of the user [28], and Berthouze shows that a high level of motion modifies the way in which users get engaged by displacing the experience "from hard to easy fun" [3]. The promotion of an attitude of active engagement and the consequent motivational factor are extremely important in the context of a learning environment. Learning tends to be more effective when it is associated with a feeling of "personal investment" and when it is driven by an endogenous motivation [9]. These affects provide the learning process with a purpose that is meaningful for learners [36] and can induce a flow state in which the learner becomes fully involved in a motivating activity [1].

3. INTERACTION AND EXPERIENCE DESIGN

3.1 Conceptual framework

In order to create a meaningful activity on the Interactive Slide, we oriented user experience design toward exploiting the role of kinesthetic perception and sensorimotor experience as tools to facilitate learning. For this reason, the application design has favored an approach that would stress the natural mapping between the physical properties of the Slide, the sensorimotor experience that it offers and the specific content of the application.

Considering that the most significant kinesthetic experience offered by the Interactive Slide is related to "sliding down", we concentrated our interest around phenomena linked with gravity and we choose to work around concepts related to Archimedes' principle i.e. mass, density, gravity and buoyancy.

After searching educational standards and issues related to common misconceptions about the science content [22,24,37] we developed the learning strategies and the application gameplay.

For the development of the "Archimedes" application we based our approach on the integration of the frameworks proposed by Rieber [34], which combines the features of simulation with the attributes of game and the model of Problem Based Games proposed by Kilii et al. which suggests a learning strategy based on problem solving to develop hypothetic-deductive reasoning and support metacognition [36].

3.2 Application development

We designed a simple problem solving game based on Kilii's framework, which suggests a design strategy where learning is generated through the process of working toward solving a problem encountered in the game [20].

The game, named "Archimedes", was projected on the sliding surface of the Interactive Slide and children could interact with it by sliding down.

The game's environment consists of a landscape with two pools of water divided by a central piece of land. Four characters appear: a pink fish in the left pool, a green fish in the right pool, a cat trapped in the central piece of land and a mouse standing on the left piece of land.

In the upper part of the play area, three types of virtual objects appear randomly from the right and move across the top until they exit through the left. The three types of objects are: rocks, logs and beach balls (Figure 2). Children may interact with these objects by sliding down over one of them and dragging it down into the pools.

The gameplay of “Archimedes” was based on solving a problem-based puzzle: children had to help the green fish jump into the left pool to join the pink fish and help the cat catch the mouse. However, the water level is too low to allow the fish to jump and the cat does not like getting wet and can therefore not cross the left pool to reach the mouse.

Therefore, children had to understand the physical behavior of the objects and make a strategic use of them, since their amount is limited.

Figure 2: Scenario of Archimedes application.

As per their simulated physical density properties, the rocks sink to the bottom of the pool and, by Archimedes’ principle, raise the water level proportionally to the volume of water displaced by the volume of the rock. The logs float but keep half of their volume under the water and the other half above. Therefore, they can be used both to slightly raise the water level and to create a floating bridge that allows the cat to cross over. The beach balls float completely above the water and therefore do not raise the water level at all, however they can be used to accelerate the rising of water if they are trapped in the cavities of the land.

By actively playing children observe and have to understand these specific properties and laws in order to solve the problem.

If they succeed in raising the water level of the pools sufficiently to allow the green fish to jump, and in building a bridge for the cat, they solve the problem. Instead, if they end up using all objects before solving the problem, the game is over.

The game is presented as a collaborative experience and is based on one single level of difficulty.

4. EXPERIMENTAL DESIGN AND PROCEDURE

4.1 Experimental Design

The main hypothesis of our research project was to test whether the physical activity on the Interactive Slide supports the understanding of the application’s science content. This should be achieved through the embodied experience that emerges from the relationship between Slide's affordances and the sensorimotor experience that it generates.

In order to test this hypothesis we designed an experimental procedure organized in three steps: the first aimed at evaluating the educational effectiveness of the Archimedes' application, the second one oriented toward assessing the effects produced by the specific use of the Interactive Slide as interface, and the third one aimed at checking the reliability of the procedure.

To check the effectiveness of the Archimedes application we used a repeated measure experimental design based on the administration of pre and post-test questionnaires, aimed to measure learning through the comparison between pre and post-test scores.

The hypothesis has been formalized as follows:

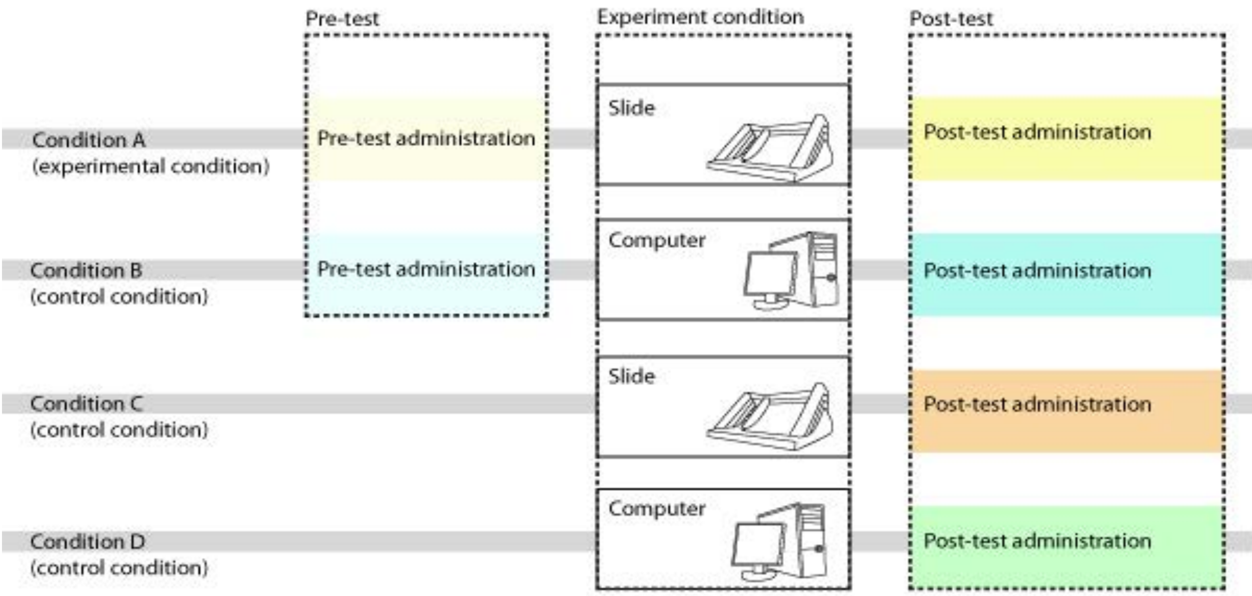

Figure 3: Solomon design distribution for Archimedes project: conditions and variables.

H1a: There is a significant difference in the mean scores between pre-test and post-test, due to the use of the Archimedes application.

We then proceeded with testing the specific effects produced by using the application on the Interactive Slide. In order to test this variable we designed a comparative experiment to test the use of the application on two different interfaces.

based on the use of the Archimedes application on the Interactive Slide, and the Control condition, based on the use of the same application on a desktop computer interface. The scores of the Experimental and Control condition have been contrasted in order to test the effect produced by the interactional difference on the learning process.

The hypothesis that led this experimental design was formalized in the following way:

H1b: There will be a significant learning gain, in children that use the application on the Interactive Slide with respect to those that use the application on the desktop environment.

Finally, we proceeded with the assessment of the methodological reliability of our experimental design, by checking for potential bias caused on scores by the administration of the pre-test.

Several studies show that the administration of the pre-test can produce a sensitizing effect on post-test scores [8]. In order to check whether the improvements in scores were really due to the application experience and not to the pre-test administration, we decided to use an experimental design based on Solomon four group design. This design contains two extra control groups –one in the Slide condition and the other in the Desktop condition- that do not have pre-test administered in order to reduce confounding variables due to the influence of the pre-test.

This test has been operationalized using the following hypothesis:

H1c: there will be no significant difference in the post-test scores between the participants assigned to the control condition without pre-test and the participants assigned to the experimental or control condition with pre-test.

Finally children were tested on the level of enjoyment of the application and on their willingness to repeat the experience.

In the following sections provide a detailed description on operationalization, demography and procedure.

4.1.1 Apparatus

The main objective of this research was to evaluate the impact of the Interactive Slide as a learning environment through the comparison between the effects produced by the use of different types of interfaces. To evaluate the interactional difference we used an informational equivalent content –the Archimedes application– on two different kinds of interfaces: the Interactive Slide and a desktop computer with mouse control. This choice is based on the idea that computer based interaction is actually the most known and the most used kind of interactive technology. Moreover, the personal computer, for its own conformation, strongly contrasts with an approach based on the integration of sensorimotor skills into everyday activity.

As the Interactive Slide supports multiple players at the same time we decided to implement a collaborative mode of playing also on the personal computer interface. Children were invited to play in groups of four either with the Interactive Slide (Experimental condition) or with the desktop computer (Control condition).

In order to allow each group to build its own collaborative strategy, we did not give them any clues related to specific modes of collaboration.

4.1.2 Assessment

For the assessment methodology we focused our attention on learning gains, through the operationalization of learning goals related to the use of the Archimedes application.

Learning processes were evaluated through the use of a multiple-choice questionnaire.

The questionnaire was structured as follows:

- Three questions on intuitive understanding and formation of concepts of density, mass, volume and Archimedes' Principle
- Four questions on the capacity to identify regularities in elements behavior and infer conclusions from observations
- Three questions on problem solving skills
- Two questions on transfer ability

The questionnaire was designed through the consultation of existing educational materials about methodologies for designing multiple-choice questionnaires [10] and for the evaluation of scientific contents in primary and secondary school [21], and was tested on five participants whose average age was twelve years.

During the experiment, the same questionnaire has been administered twice in children assigned to pre and post-test condition and once to children assigned to post-test condition only.

4.2 Experimental Setup and Protocol

In order to test our hypotheses we used a mixed experimental design that combines a repeated measure pre and post-test design with independent samples assigned either to the Experimental or the Control conditions. This method was reinforced by adding two more control groups according to the methodology proposed in the Solomon four group design.

The independent variables we used were related to the type of the interface and to the administration of the pre-test. Participants were randomly assigned to four different conditions (Figure 3) according to the following variables (Table 1):

A) Experimental condition: Use of a **collaborative exertion interface,** the Interactive Slide, and pre and post-test administration

B) Control condition 1: Use of a **collaborative non-exertion interface,** the desktop computer, and pre and post-test administration

C) Control condition 2: Use of a **collaborative exertion interface,** the Interactive Slide, with post-test administration

D) Control condition 3: Use of a **collaborative non-exertion interface,** the desktop computer, with post-test administration

4.2.1 Sample

A total of 331 participants successfully completed all the experimental procedure. Participants were recruited from 5th and 6th grade of primary school and their ages were comprised between 9 and 12 years old with a mean of 11 years old.

Schools were randomly selected from different neighborhoods of the city. When we contacted the schools we ensured that children did not have any prior knowledge of the Archimedes principle or the concept of buoyancy.

The experiment took place in a multipurpose space –where the Slide was set, and the Full-body Interaction Laboratory –where the questionnaires were administered, and the participants who belonged to the control condition used the desktop computer application.

4.2.2 Procedure

The experiment was carried out in a three weeks period. Each class-group spent two hours and half in the university and participated in two experiments related with two different applications for the Interactive Slide.

Children first participated in the "Balloons" project, which is an interactive game aimed at promoting physical activity in children, and then they participated in the Archimedes experiment. This structure allowed children to get familiar to the Interactive Slide, as a platform and as an experience, before using the Archimedes application. This way we minimized biases related to the novelty factor within the learning environment. The schedule of the experiment was structured as follows:

- Initially children were randomly divided into groups of four.

- Each group was assigned to the A (or C) condition or to the B (or D) condition.

- Children assigned to the A or C condition started the "Balloons" experiment, while children assigned to the B or D condition were accompanied by a facilitator and a teacher to the Laboratory where they completed the Archimedes pre-test questionnaire.

- Subsequently groups were exchanged and children who played with "Balloons" answered the pre-test while the others played with "Balloons".

- When all the children finished with both the questionnaire and the "Balloons" experiment they were gathered at the Slide Room where the facilitator gave a short introduction to the Archimedes activity by explaining the main goals of the game. The instructions were focused on explaining only the objectives of the game without giving any clues on how to solve the problem.

- Subsequently the children assigned to the A or C condition remained in the Slide Room and used the Archimedes application on the Interactive Slide platform, while the children assigned to the B or D condition were taken to the Laboratory and used the Archimedes application on the desktop computer platform.

In both cases, when all children had finished the game, they were asked to complete a post-test questionnaire.

5. RESULTS

The experimental distribution of the 331 children was as follows:

Table 1: Sample final distribution

Condition	Interface	Test	Participants	Grade
A	Slide	Pre-test, post-test	96	6°th
B	Computer	Pre-test, post-test	89	6°th
C	Slide	Post-test	80	56: 6°th 24: 5°th
D	Computer	Post-test	66	46: 6°th 20: 5°th

To test the effectiveness of Archimedes application and the effects of the interactional difference we used data from conditions A and B; to check for sensitizing effect of the pre-test and the level of enjoyment we used data from all conditions.

Scores for the questionnaires of all participants were calculated by assigning one point for a correct answer and zero points for the incorrect answer. Normality assumption was checked for all conditions using a Shapiro-Wilk test.

Data were not normally distributed in any conditions, so non-parametric tests were used.

A short description of results and statistic procedure is described in the following sections; for a summary of the results see tables 2 and 3.

5.1 Test of the effectiveness of the Archimedes application

Wilcoxon Signed test was used to run the comparison between pre and post-test scores in both conditions A and B.

A statistically significant difference between the scores of pre-test and the scores of post-test was found for Condition A (sig= 0,047, Z= -1,983) with an increase in post-test scores (positive rank = 40,09, negative ranks = 37,30).

Instead no statistically significant difference was found between the scores of pre-test and post-test (sig= 0,105, Z= -1,621) in Condition B. However, the results indicate a tendency toward improvements in post-test scores (positive rank = 37,79, negative rank =31,37).

5.2 Test of the interactional difference between the use of two different kinds of interfaces

Mann-Whitney U test was used to run:

- the comparison between the post-test scores of Condition A and the post-test scores of Condition B

- the comparison between the percentage increase for Condition A and Condition B

The tests show no significance difference between post-test scores in Condition A and B (sig = 0,291, Z= -1,056), nor between comparison of percentage increase (p= 0,742, Z = -0,329). However, the mean rank for Condition A (94,24) was higher than the mean rank of Condition B (91,66).

5.3 Test of the sensitizing effect of the pre-test administration

A Kruskal-Wallis test was run to assess whether there was any significant difference between post-test scores of the four conditions. The test shows a significant difference between the scores of the four conditions (chi square=10,343, sig = 0,016). Mann-Whitney U follow-up test was run to assess for difference in pairwise comparison.

Results show significant difference in post-test scores between condition A and C (sig = 0,048, Z= -1,974) and between condition B and C (sig = 0,007, Z= -2,698).

Instead no significant difference was found between condition B and D (sig = 0,441, Z= -,823) nor between condition C and D (sig = 0,266, Z = -1,113).

5.4 Test of the level of enjoyment

We finally proceeded with testing the level of enjoyment of participants. Questions about enjoyment were included in the post-test questionnaire and based on a Likert scale model. Mann-Whitney U test was used to compare between participants assigned to Slide Condition (A and C) and Desktop Condition (B and D).

Results show significant difference in the level of enjoyment both between Condition A and B (sig = 0,006, Z =-2,768) and between Condition C and D (sig =0,001, Z= -4,481).

Table 2: Test of application's effectiveness and interactional difference

	Condition A Post-test	Condition B Post-test
Condition A Pre-test	Sig= 0,047, Z= -1,983	
Condition A Post-test		Sig = 0,291, Z= -1,056
Condition B Pre-test		Sig= 0,105, Z= -1,621

Table 3: Test of the sensitizing effect of the pre-test administration

	B post-test	C post-test	D post-test
A post-test	Sig= 0,291, Z= -1,056	Sig= 0,048, Z= -1,974	
B post-test		Sig= 0,007, Z= -2,698	Sig= 0,441, Z= -,823
C post-test			Sig= 0,266, Z = -1,113

6. DISCUSSION

The study has revealed three main results about the use of the Archimedes application.

The Wilcoxon Signed test conducted to evaluate the effectiveness of the use of Archimedes application shows a tendency toward increase in the scores related to the understanding of Archimedes' principle.

However, even if the increase in scores between pre and post-test were present in both conditions A and B, it is relevant to notice that improvements are statistically significant within Condition A (Slide) (p = 0,047, Z= -1,983), while they are not statistically significant in the Condition B (Desktop) (p = 0,105, Z= -1,621,).

These results may suggest the possibility that the Slide could be more effective than the desktop computer as an interface for learning abstract concepts related to physics; however the test related to the effects of the interactional difference shows that there was no significant difference in the comparison between the scores of post-test of conditions A and B (p= 0,291, Z = -1,056).

Despite this lack of a statistically significant difference it is important to underline that we did find a significant difference in the level of enjoyment (sig =0,006) which suggests that the group playing on the Interactive Slide enjoyed more the experience than the groups assigned to the desktop computer.

These results show the potential of the use of the Interactive Slide as a learning environment, and suggest the possible benefits of using it as a platform for educational contents.

However, in order to better capitalize the properties of the Slide, further research is necessary to optimize the design strategy. In the current application we focused on a transfer between the gravity experienced in the Slide and the gravity related to the Archimedes principle. It is possible that this strategy has not been particularly effective due to the weakness of the mapping between action, embodied cognition and concepts. It will be useful to try other possible mappings between experience and content by focusing more on the features of the Slide as gravity and forces related to the inclined plane.

At the same time it will be necessary to improve the assessment methodology because the procedure used for evaluation presented issues related both to reliability and to administration. During the administration of the questionnaires we faced some issues related to the willingness of children to complete them. Practical problems arose from the fact that some children did not understand the reason for having to do the same test twice, or refused to complete it or paid little attention to the performance of the task and delivered it incomplete. Possible problems could be found in the length of the test and in the fact that it repeats exactly the same structure both in pre and post-test.

Tests conducted to assess the sensitizing effects of the pre-test show that the administration of the pre-test had an influence on the improvements of the results, which is significant in the Condition A (sig = 0,048) and not significant in the Condition B (sig = 0,441).

These results show two main effects of the pre-test administration. On the one hand, it worked as a clue to improve the results in the test, through the socialization of the correct answers during spare time or through self-correction strategies. On the other, the difference between the pre-test effect in the Slide condition and in the Desktop condition suggests that it is possible to hypothesize that the administration of the pre-test may have played an important role in the process of upgrading from concrete experience to abstract knowledge, by altering the context situation. This could have had relevant effects by varying the attentional focus of participants [23] and by modifying their selection of important information.

This hypothesis can offer some important clues to design a more complete learning environment for the Interactive Slide that could benefit from the feature of the whole context in which it is located.

7. CONCLUSIONS

In this paper we have presented the design, development and testing of the Archimedes application as a first educational application for the Interactive Slide. The application, aimed at fostering learning about buoyancy and Archimedes' principle through the use of physical activity and sensorimotor experience, served as a pilot study of the Interactive Slide for educational purposes.

The experimental design, in which we compared the use of the Archimedes application on two different kinds of interfaces (Interactive Slide and desktop computer), showed a significant improvement in scores in the use of the application with the Slide, while no significance is reported in the use of the application with the desktop computer.

Even if the difference between improvements in the Slide (Condition A) and Desktop (Condition B), was not strong enough to be statistically significant, these results can be considered as a good starting point to encourage further research related to the use of the Interactive Slide as an educational platform.

This research, by showing positive outcomes of the use of the application with the Slide, confirms the importance of the role of body and action in learning processes [7,23,32] and opens interesting research perspectives about the educational impact of the physical interface in terms of affordances and kinesthetic experience.

This triangular relation between physical interface, action and agent is consistent with the enactive approach which affirms that meaning construction belongs to the relational domain established between the environment and the agent [11] and reinforces the hypothesis of Manches *et al.* regarding the possible implications of physical artifacts in fostering the development of concepts.

Moreover, the results confirm the outcomes of the research that relates physical activity with increased engagement [3,32] and enrich the state of the art about the inclusion of physicality in educational contexts as a tool to allow the transfer from experience to abstract knowledge.

As a final remark, we believe that these results open a useful field to explore the effects of the physical interface and embodied interaction in the learning process. These allow for further exploration on the role of physical artifacts and kinesthetic experience in the knowledge construction. They can encourage the development of novel educational applications for the Interactive Slide.

We consider this work as a first exploratory study in the path for developing more effective educational applications for the Interactive Slide platform. However, it will be necessary to better capitalize the properties of the Slide to deepen in the relationship between the physical structure and the learning content, to reformulate the assessment methodology and to improve the evaluation strategy of the effects of the interactional difference.

8. FUTURE WORK

During the process of design and analysis of the Archimedes application, we have found some challenges that might guide future work related to the development of educational applications for the Interactive Slide. These challenges may be divided into two main frameworks.

The first challenge presents the opportunity to improve and enhance the application design by establishing a more significant mapping between the content of the application and the actual sensorimotor experience produced by the use of the Slide. This can be addressed through the implementation of smaller-scale studies, cooperative inquiry methodologies and user and teacher interviews during the design phase, in order to identify learning problems and improve design strategies.

Another possible improvement of the application could be related to the implementation of "microworlds" structure, understood as the possibility of the learners to regulate their own learning through the setting of different level of difficulties [34].

The second challenge is the improvement of the assessment methodology, and it represents the most challenging objective for future works.

Many studies, aimed at assessing learning in an environment based on physical activity, make use of praxeological methodologies [5, 23, 27] related to the ability to perform intelligent actions and express knowledge through body behavior.

However these approaches, by focusing on a kind of "know-how", do not ensure that this knowledge could be available for formal and explicit thinking, because as Broaders *et al.* point out, the information that learners express in gesture and not in speech is often unique to gestures [6].

Therefore is necessary to think about a methodology based firstly on assessing the presence of an implicit knowledge in gesture, movement and behavior during the game; and at the same time able to test the concepts in terms of propositional knowledge.

Possible strategies to achieve these results could be to combine a praxeological approach based on analysis and coding of intelligent actions with methodologies that allow self-reflection about the learning experience, as it could be methods based on ethnographic approaches as learning talks [1], interviews, open-ended questionnaire or behavioral performance.

For further development it would be necessary to build a robust assessment methodology able to properly evaluate the effect on learning of specific interaction types and avoid bias related to the sensitizing effect of repeated measures.

Other factors that could be included into a more complete assessment methodology can be related to the evaluation of the problem solving strategies and to the observation of the adopted collaboration modalities. From short informal talks carried out with the children after the experimental procedure, the use of different strategies of collaboration and problem solving emerge within the different groups. Some groups played with a specific work shift, others established a task division while others didn't decide any previous agreement about how to organize themselves.

These factors could have played a significant role in the learning process; it is therefore necessary to include their evaluation into the analysis of learning outcomes.

Finally, to foster improvements in both the design and the evaluation, it should be necessary to focus on the inclusion of the context situation in the process of designing the learning environment [41] and in the process of analyzing it.

Possible suggestions could be related to the design of a complete learning environment, able to orient the understanding of the experience and offer cues to facilitate the building of a clear correspondence between provided information and learning goals. However, this strategy should be accurately tested through the manipulation of its features within an experimental design.

9. ACKNOWLEDGMENTS

The authors wish to thank Joan, José Maria and David for their efforts in programming the application and made this project possible and to Pascal, Anna and all the people who helped in setting up the experiments and taking care of the children. Finally, the authors wish to thank all the schools that collaborated in the experiment.

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