TALKING PHYSICS IN INQUIRY BASED VIRTUAL LABORATORY ACTIVITIES

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ABSTRACT
This study refers to secondary students working in a simulated virtual open laboratory environment using "Thermolab", following an innovative course on thermal phenomena, being engaged in a variety of activities, ranging from "structure lab" with a teacher-defined setup, to "student directed inquiry" with investigation characteristics. Students were working in pairs and data were collected by video and audio recording. The research question under investigation is: "how is the density of verbalization of students' knowledge affected by the type of activity they are engaged in an open virtual laboratory?" Analysis of students' actions and conversations, concerning five different laboratory sessions, is based on a method called CBAV (Category Based Analysis of Videotapes) according to which, the density of students' knowledge verbalization is related to specific lab-work contexts and can be used as a measure of the linking between theory and practice during lab-work. Our findings reveal that while experimenting in a virtual laboratory environment, our students create links between theory and practice, but these are more likely to occur while working in investigative type activities, rather than working with a teacher-defined setup.

KEYWORDS
Category Based Analysis of Videotapes, Virtual Laboratory, Inquiry

INTRODUCTION

During the last few decades, there is an on going conversation about the role of labwork in Science Education, revealing the interest in this field not only from the educators' side, but also from the researchers and the authorities(Wellington, 1998; Woolnough & Allsop, 1985). In this context, many researchers have expressed their concern about the efficiency of labwork in fostering students' understanding of the various aspects of scientific investigations. As a result a reconsideration of the aims of labwork has been proposed and also a further research on the learning gains among various labwork contexts (Lazarowitz & Tamir, 1994; Lunetta, 1998; Tobin et al., 1994). It is also been suggested that there is a need for further investigation in the relation between laboratory activities and the learning accomplished during labwork (Leach & Paulsen, 1999). Labwork is considered important in science education, because the understanding of science developed in the laboratory, not only includes the learning of concepts and models of science but also the development of skills concerning the scientific investigation of the field under study. Students get in touch with the world of ideas, representing the world of objects, and are engaged in observations and interactions, while being involved with actions on specially constructed or common life objects and equipment (Psillos & Niedderer, 2002). This way, it is considered that during labwork declarative and procedural knowledge are interconnected, and students should use these simultaneously in order to be engaged in effective laboratory activities (Sere, 1999).

The effectiveness of various types of labwork has been investigated from different points of view (Ganiel & Hofstein, 1982; Lazarowitz & Tamir, 1994; Lunetta, 1998; Tobin, et al., 1994; White, 1996). According to Psillos & Niederrer (2002), the focus of the investigation should not only be about the learning of concepts and scientific procedures, but also about how students intervene in the world of laboratory and administer the entities of that world. Their suggestion is based on the fact that whilst teachers' and curriculum designers' intention is to involve students in various activities aiming in learning the use of devices or in interpreting simulated models using ICT's, acting on objects, ideas or experimental data, research has prove that students carry their own perceptions and aims about laboratory work, as for example to find the correct answer to the questions or just fill-in the worksheets. This fact leads to a mismatch between the intended aims of labwork and the actual activities of the students (Lunetta, 1998).

According to the fore mentioned researchers, this mismatch has to be investigated, as the understanding of science requires students' involvement in specific ways of intervention to the world of objects and also a valid and reliable connection of students' actions with the world of ideas. In this context, they suggest the evaluation of the quality of a given laboratory activity, by linking it to a specific type of effectiveness, called effectiveness 1 (R Millar et al., 1999; Psillos et al., 1998). In their view, effectiveness 1 can work as a two-way approach in revealing the complex interplay between theoretical representations and practical activities and the linking between them, which takes place during a laboratory activity. On the other hand, the evaluation of student learning in relation to the learning objectives is linked to another type of effectiveness, called effectiveness 2. This is the kind of evaluation widely and traditionally used for investigating the quality of labwork activities, on the basis of students' learning achievement after the completion of a piece of labwork.

Based in the work of Millar et al. (2002) and the aims of labwork that teachers set as important for laboratory work (Welzel et al., 1998), three major objectives can be defined:

- A. The students' linking between theory and practice
- B. The students' developing experimental skills
- C. The students' getting to know the methods of scientific thinking

All three of the above objectives can be evaluated in relation to both kinds of effectiveness, as described earlier. For example one could evaluate the students' linking between theory and practice (objective A) during labwork activities (effectiveness 1), or could evaluate students' knowledge with respect to the link between theory and practice after labwork (effectiveness 2), with tests and interviews.

In this work, adopting the model proposed by Psillos & Niederrer (2002), we aim at evaluating the objective A: students' linking between theory and practice, in respect to effectiveness 1. In detail, we are investigating whether students create links between theory and practice during labwork, and further more if this is related to the kind of activity they are engaged in, while working in a simulated laboratory environment called 'Thermolab'(Hatzikraniotis et al., 2001; Zacharia et al., 2008).

EVALUATING THE EFFECTIVENESS 1 OF LABWORK

Different methods have been proposed for the evaluation of the effectiveness 1 of labwork in relation to the objective A. For example Becu-Robinault (2002) analyses transcripts from labwork with respect to the connections made by students between the world of theory and models and the world of objects and events. Other researchers (Buty, 2002; Hucke & Fischer, 2002; Kirstein & Nordmeier, 2007; Sander et al., 2002; Theyßen et al., 2002) use a method called Category Based Analysis of Videotapes (CBAV), proposed by Niederrer et al. (1998). According to this method, they analyze how often and in witch contexts students talk about physics (i.e. use physics concepts related to the activity) during labwork. With this method, effectiveness 1 can be evaluated by relating the amount (density) of students' verbalisations of knowledge, to specific labwork contexts like: taking measurements or manipulating apparatus or interacting with the tutor. CBAV is a detailed in-depth study and applications of this method can also be found with variations. Recently, Scharfenberg et al. (2008), used this method to identify different student profiles based on their activities time budget during laboratory group work, while Enghag et al. (2007), measured and compared the number of students' expressions in 5 minute intervals, concerning physics in the one hand and everyday-life experience on the other, during a group discussion about solving a Content Rich Problem.

Calculating density of knowledge verbalisation

In order to calculate the density of Physics Knowledge (KP) in a given laboratory context X, one has to count all time units where students work in context X, e.g. using the labguide (LG). Then the time units with verbalisation of physics knowledge (KP), while being in this context X, is detected and their number is counted. The ratio of the number of time units with KP divided by the total number of time units in this context X (multiplied by 100) then results in what is called the density. This results in the following formula:

$$Density(KP/X) = 100 \cdot \frac{\sum Timeunits\_KP\_in\_X}{\sum all\_Timeunits\_X}$$

The categories related to labwork context are more or less obvious and are defined on the basis of the sources that students use, such as various devices or measuring instruments, labguides or interactions with the tutor. Similar categories have been used by other researchers as well (Kyle et al., 1979; Okebukola, 1985; Tamir & Lunetta, 1981). Different researchers, nevertheless, might be using different contexts, depending on their research interest and the laboratory resources available to the students. For example Buty (2002) is using a 'use of the model' context, when students are working with a simulation software in optics. On the other hand, time units should not be mistaken for seconds or minutes. In most of the cases time unit is set to 30 seconds, as this amount of time is considered adequate for a student to express a verbal statement, and can be coded in the respective verbalisation category.

As a general trend concerning the above mentioned studies, the results point out that during labwork, students do not to a large extend, employ the theoretical explanations offered in their lectures or course-texts. Additionally, time consuming activities, like taking measurements or manipulating apparatus, have a comparatively small contribution in allowing students to link theory and practice.

Based on these last findings, it seemed very interesting for us, to investigate and evaluate using the CBAV method the effectiveness of labwork, where students are engaged in activities based on a technology enriched environment of a simulated virtual laboratory 'Thermolab', where many of the time consuming manipulations of traditional practical work are substituted with actions on virtual objects.

THEORETICAL BACKGROUND

The basic assumption in this work is that students' involvement in investigative type laboratory activities, using a virtual laboratory computer based environment related to thermal phenomena, can contribute in students' developing links between the world of ideas and the world of objects and events. It is also assumed that investigative activities are related to the understanding of science modeling in the one hand, and the application of laboratory practices on the other hand, through which students are engaged in a meaningful observation and intervention to the world of objects, linking the phenomena under study with their theoretical representations (Psillos, 2007). At this point we have to clarify that the reference to objects does not only apply to the physical world, but also to the computer simulated world, where students interact with virtual objects in the computer screen. This view is totally supported in the specific virtual laboratory 'Thermolab', used in our study, since one of the basic characteristics of 'Thermolab' is the life-like representation of the setting, the apparatus and measuring devices, and also of the procedures and manipulation of the virtual objects, through which students intervene in this virtual world. The importance of this intervention offered to the students for the learning of science and for the desired linking between theory and practice, is supported by Tselfes (2002): 'science is not only constructed by representations of the physical world, but also includes methods of intervention to the world, especially in the laboratory where scientists endeavor is to investigate and match up the experimental data with the corresponding theoretical models. This intervention occurring in the laboratory, is considered a part of the science tradition and a distinctive inherent characteristic of the practical sciences, allowing the interactions between the physical entities and the theoretical statements, thus discriminating practical sciences from other areas of knowledge'

METHODOLOGY

Application of the CBAV method: choices & assumptions in this work

Since the application of the CBAV methodology allows tailoring to the different needs of each research, there are some choices and assumptions taken in this work to be mentioned:

A) The first choice was to keep the time interval for the data collection to 30 seconds, as in the original proposal of the method by Niedderer et al. (1998), i.e. in the Density formula above: Timeunit = 30 sec.

B) Another methodological problem to be solved came from the fact that while students were working in pairs, each pair needed a different amount of time for completing each activity. Consequently, for the faster pairs, there was some kind of 'wait time', until the other students also completed the activity, and the whole class was ready to discuss their results. This 'wait time', was not accounted for the calculation of the Density. So, in order to calculate the Timeunits, we consider as starting point, the moment that the Worksheets were handled to the students, and as a finishing point, the moment that each pair gave them back to the tutor after completing each activity. This way, the amount of Timeunits is different for each pair, but we are still allowed to compare them, as in the CBAV method verbalisation is calculated as Density (i.e. as percentage of the total time of each pair) and not as an actual value.

C) A third choice was about the recording of knowledge verbalisation regarding the two members of the pair. In the original proposal of the method, both members of a pair are considered as commonly contributing in each Timeunit, in other words, if both are expressing verbalisations only one contribution is recorded. On the other hand Theyßen, et al. (2002), uses a different approach, recording separately the contributions of each student, regardless if they were expressed in the same Timeunit. This was also our choice, as the contributions from each member of the pair were recorded, and the mean value of contributions was then used for the calculation of the Density.

D) Following the original CBAV methodology, we also made the choice of recording data in more than one verbalisation categories, even if they appeared in the same Timeunit. And this was also the choice of Buty (2002), who took a step further and calculated the sums of Density in categories of verbalization considered as related. For example, we can calculate the sum of all verbalization categories related to Physics (in our case Physics Theory and Physics concerning properties of the Virtual objects), while students are working in a specific laboratory context (in our case 'Thermolab').

E) One last point worth mentioning is that during the application of the CBAV method, and before concluding in the analysis discussed in this paper, a broader list of categories of knowledge verbalisation and labwork contexts were coded and recorded, but are not presented here. This work only refers to the categories related to students' working with the virtual laboratory 'Thermolab'.

Research Question

Following our theoretical background, our research question is: 'how does the engagement of the students in different types of laboratory activities with manipulations of virtual objects and devices in 'Thermolab', affect the density of Physics Knowledge verbalisation?'

In order to answer this question, we have used the CBAV method, firstly for measuring and then for comparing the knowledge verbalisation density, between different types of laboratory activities. Recently, Du et al. (2005) developed a fairly general process to describe design steps for an experiment In their scheme, they have classified in-class experiments from "demonstration and cookbook lab" to "student-directed and student-designed inquiry", identifying six levels: Lecture/Demo, Cookbook Lab, Structured Lab, Challenge Lab, Student-Directed Inquiry and Student-Designed Inquiry. As one moves along the scale, the responsibility for the various tasks gradually shifts from teacher to student.
In this work we are concerned about two types of activities. One type of activity called 'closed type' refers to the structured lab where, the experimental procedure was pre-set and students reach own

conclusion based on evidence. One other type of activity, called ‘open type’, refers to a student directed inquiry type situation, where students are asked to create an appropriate experimental set-up in order to solve a given problem. In this case, students are offered an open space for intervention, and are allowed to do any possible manipulation (within the boundaries of the virtual world).

Research context

The subjects of our study were 14, comprising all second form students (13-14 years of age) of a typical class in a small secondary compulsory school, following an innovative teaching sequence with a strong laboratory character enriched with ICT. The teaching sequence covered topics concerning Thermal Phenomena included in the Greek curriculum of compulsory education. Students were familiar in using computers and “Thermolab” before teaching, and worked in pairs, each pair having their own computer and worksheets. The teaching model was a mix of theory and laboratory sessions. Students’ conversation was recorded in video and also in audiotapes, in order to assure the best possible recording quality of the sound of the 7 pairs working simultaneously in close vicinity.

The results reported below in this work, concern the application of the CBAV method, to the conversations of two pairs of students while working in 2 different laboratory activities using ‘Thermolab’. These activities (Table 1) were selected from the teaching sequence as representatives of the ‘closed’ and ‘open’ type, described earlier, in order to provide testing ground for our research question. Both activities refer to investigations about Thermal Radiation and this way they also share the same conceptual content, as presented below:

<u>Radiation.1</u>: In this activity students are guided to realize the relation between the color of a body and the rate of thermal radiation emitted. They are working in Thermolab, conducting an experiment where a black and a white painted beaker containing the same amount of water of the same high initial temperature are placed in a colder surrounding temperature. The objective is to measure the time necessary for each beaker to reach the final temperature, thus concluding on the effect of each color to the emition of thermal radiation.

<u>Radiation.2</u>: In this activity students are investigating the relation between the total surface of a body and the rate of thermal radiation emitted. They are working in Thermolab, using the objects, apparatus and initial values of their choice, setting up an experiment relevant to this problem question. The objective is to measure the time necessary for bodies of different total surface, to reach the final temperature, thus concluding on the effect of surface to the emition of thermal radiation.

Table 1. The selected activities, corresponding topic and type

Activity	**Topic**	**Type**
Rad.1	Thermal radiation – bodies of different color	Closed
Rad.2	Thermal radiation – bodies of different surface area	Open

These activities are parts of larger teaching sessions lasting one teaching hour (about 50 min) each. A session like that comprises of several phases of teaching acquiring the participation of the whole class, or students’ activities working in pairs. Students are initially introduced to the topic under study and the Physics concepts involved. Then they are asked to predict the outcome of a given problem situation, based on their perceptions or preconceptions, working in pairs. Their predictions are discussed in the whole class, explaining each others thinking, but no correct answer is given from the tutor. After that, students are asked to work on ‘Thermolab’ and collect data that will lead to the solution of the initial problem. Their conclusions are discussed in the whole class and the tutor guides to a generalization. Finally, students are sometimes asked to apply these conclusions to a new similar situation.

In this work we focus on the experimentation phase, where students working in pairs are conducting experiments, either following detailed directions in their worksheet (structured lab) or taking their own decisions about the set-up and measurements (student directed inquiry).

CBAV categories for context and verbalisation

In order to apply the CBAV methodology, we have defined 7 categories concerning the laboratory context and 5 categories of knowledge verbalisation, but only a sub-set of these is used in this present report, as described in the following tables (Tables 3 & 4). In fact, we are interested only in one context category (SIM) concerning the use of the simulation, and the corresponding sub-categories: i.e. while students are setting-up the experiment, run the simulation, take measurements and record the output results to their Worksheets. Likewise, concerning the verbalisation categories, we are only interested in students' expressions about physics concepts concerning the properties of the objects (VP) or about physics theory (PT), while working with the simulation.

In a recent work, Kirstein & Nordmeier (2007), have used this same method to evaluate the use of an interactive students' lab instruction manual before using the actual equipment. For this evaluation they have defined a similar pattern for students' expressions.

Table 3. CBAV category coding & description for laboratory context

Category / sub		Code	Description	Example
Simulation	Set-up	**SIM**	Use the simulation to set-up the experiment	Students manipulate virtual objects and devices, to set the appropriate initial temperatures of water and oil
	Measurement		Use the simulation to take measurements	Students are following the progress of an experiment from the thermometers and the real-time graph, reflecting on their initial predictions
	Results		Use the Worksheets to record the results	Students are recording the data from the screen to a table in the Worksheet

Table 4. CBAV categories coding & description for verbalisation

Category	Code	Description	Example
Virtual objects	VO	Verbalization about manipulations of virtual objects and devices	Students talking about the way to empty a beaker and to refill it again
Virtual object & Physics	VP	Verbalization about physics concepts concerning virtual objects	Students talking about the temperature of water in a beaker
Physics Theory	PT	Verbalization about Physics theory or students perceptions	Students predicting the final temperature that a beaker will reach

RESULTS

Results are presented in tree aspects:

A) A cross-comparison of the total density of physics verbalisation for activities of two student pairs working with "Thermolab"

Following the CBAV methodology, the total Density of Physics Knowledge verbalisation was calculated for two activities conducted by two pairs of students. The total Density is the sum of the 2 components of physics verbalisation (VP + PT) for each one of the activities as presented in the following table (Table 5) and figure (Figure 1).

Table 5. Density of the total Physics Knowledge Verbalisation (VP + PT) of student pairs A and B, conducting the activities Rad.1 and Rad.2

	Total Density of Physics verbalisation (%) (VP + PT)	
Activity	pair A	pair B
Rad.1	36,11	45,00
Rad.2	62,50	57,69

As presented in Table 5, the total Density of physics verbalisation in the 'open type' activity is greater than in the 'close type' for both student pairs A and B. This is also clearly shown in the corresponding Figure 1.

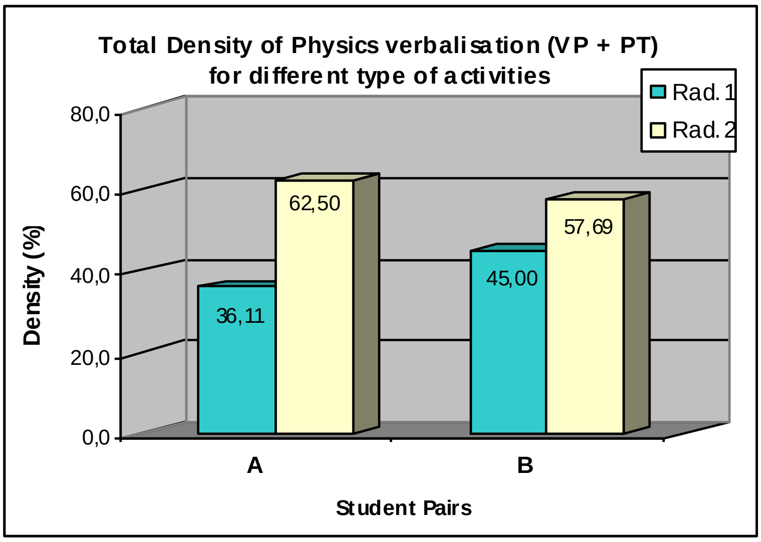

Figure 1. Density of the total Physics Verbalisation (VP + PT) of student pairs A and B, conducting the activities Rad.1 and Rad.2

B) A detailed presentation of the density of the 2 components of physics verbalisation (VP and PT) for each one of the activities

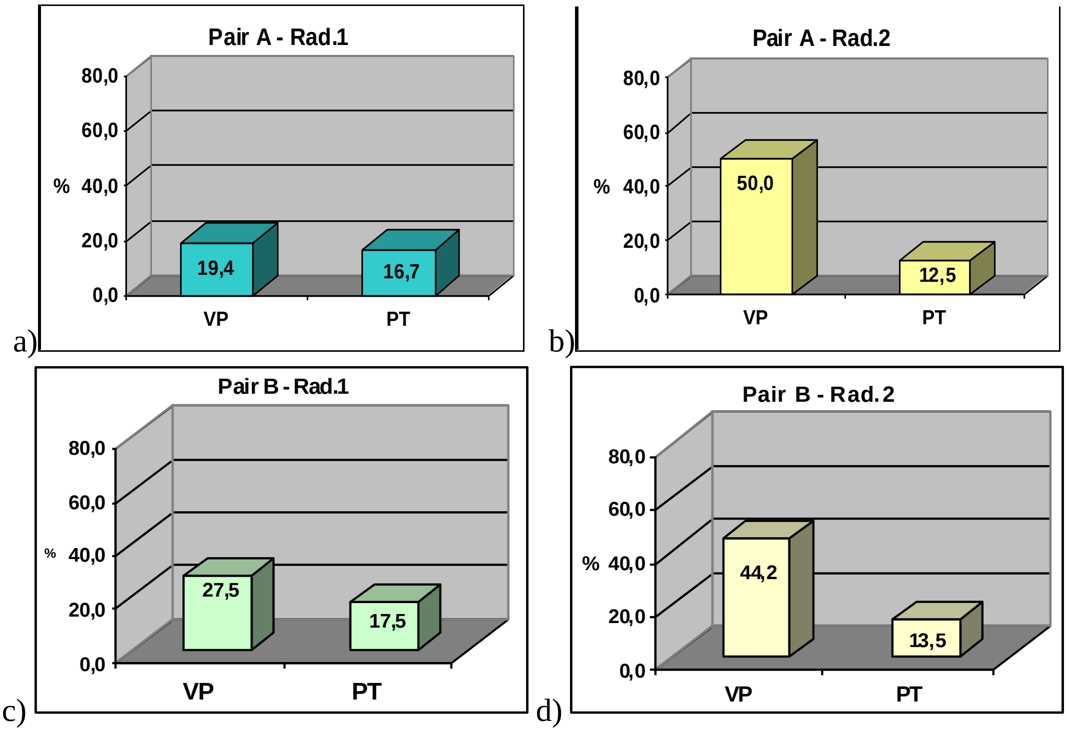

Figure 2(a-d). Density of the 2 components of physics verbalisation (VP and PT) for each one of the activities Rad.1 & Rad.2, for both student pairs.

Another aspect of the data collected with the CBAV method, is presented in figure 2. These figures show in detail, the Density of physics knowledge verbalisation calculated separately for each one of the two categories concerning physics, i.e. the verbalisation about objects (VP) and the verbalisation about physics theory (PT).

In figure 2, it is clear that for all activities the Density of Physics Theory verbalization (PT) ranges in the area of 10-20%. On the other hand, the Density of verbalisation about the physical properties of the objects (VP) is quite big for the 'open type' activity (Rad.2) but smaller in the case of the 'close type' activity (Rad.1).

C) A detailed presentation of the density of verbalisation about virtual object manipulation (VO) against the total density of the 2 components of physics verbalisation (VP + PT) for each one of the activities

A third aspect of the data collected with the CBAV method, is presented in figure 3 below. These figures show in detail for every activity, the Density of verbalisation calculated separately for the expressions concerning manipulations about the virtual objects (VO) against the total Density of Physics verbalisation (VP + PT), where total Density is the sum of verbalisation about the physical properties of the objects (VP) and the verbalisation about physics theory (PT).

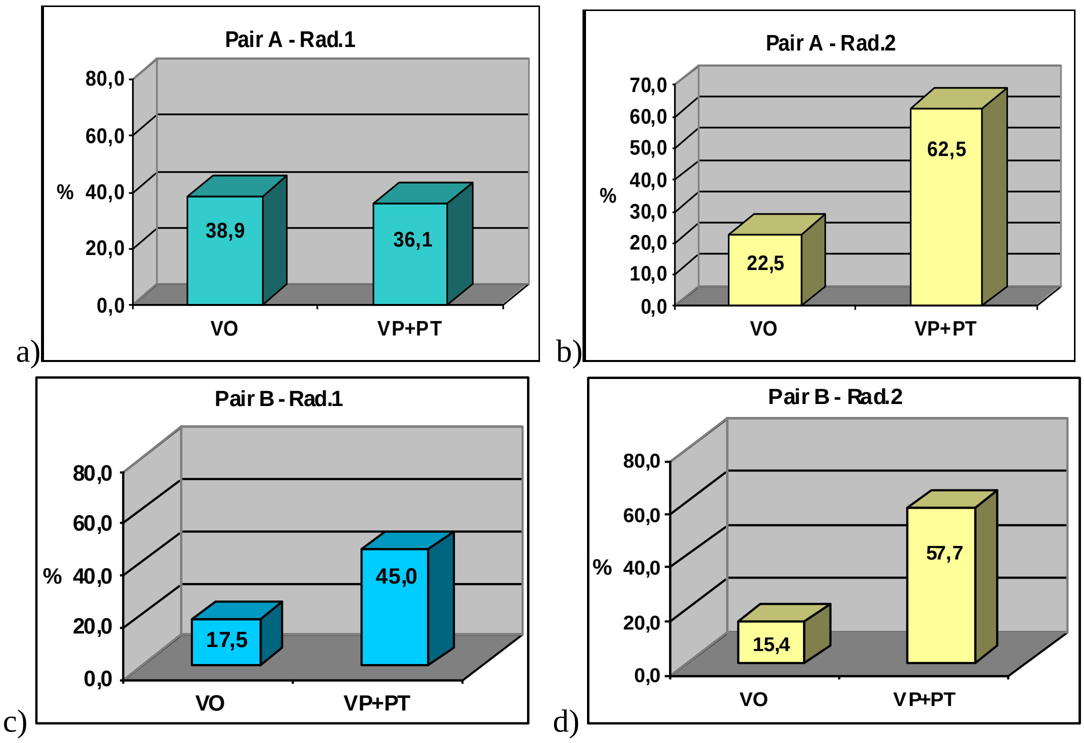

Figure 3 (a-d). Density of verbalisation about virtual object manipulations (VO) against the total Density of Physics knowledge verbalisation (VP + PT) for each one of the activities

In figure 3, it is clearly demonstrated that for the 'open type' activity (Rad.2) the total Density of Physics Knowledge verbalisation (VP + PT) in both pairs is about three or four times larger than the Density of verbalisation concerning virtual object manipulations (VO). On the other hand, in the 'close type' activity (Rad.1) the total Density of Physics verbalisation (VP + PT) is lower and for each pair the verbalisation about virtual object manipulations (VO) is grater than it was in the Rad.2 activity of the same pair.

DISCUSSION

Data presented in figure 1 (and the corresponding table 5) can give ground for answering our research question. Since there is an obvious difference in the total Density of Physics knowledge verbalization (VP+PT) between the 'close type' activity and the 'open type' ones, we are allowed to suggest that the engagement of students in inquiry type laboratory activities results in a grater density of Physics knowledge verbalisation. In turn, based on the theoretical background of the CBAV method, this means that students are creating more links between theory and practice, during an inquiry type labwork activity.

Following a more detailed analysis concerning the categories of verbalization coded in this work, we can also comment that:

- The density of verbalisation about Physics concerning virtual objects (VP), is very high in the case of the inquiry type activity and rather low in the case of the structure lab (Rad.1) and of course this is the main reason for the effect on the total Physics knowledge verbalisation (VP+PT) discussed in the paragraph above.
- In all the activities, a relatively similar Density of verbalisation concerning physics theory (PT) was observed, and this applies also to the structured or the inquiry type lab. This is in our view quite an interesting aspect about the use of the virtual laboratory, since it provides evidence about students' creating links to Physics theory, which means that a level of abstract thinking is also fostered while working in a virtual environment like 'Thermolab'.
- The fact that during a structured lab the Density of verbalisation about virtual objects manipulation (VO) is higher than the ones calculated for the inquiry based labs, appears to be contradictory, since students in the later case deal with many more manipulations of the virtual objects. But we have to remind here that Density is a relative and not an absolute quantity, calculated on the basis of the total time of the activity, meaning that if an activity lasts for a shorter time (as expected for a structured lab), the same amount of verbalisation results to a grater Density.

CONCLUSIONS

The background aim of our study was to investigate aspects of effectiveness 1 in labwork, concerning the linking between theory and practice. This was accomplished by a detailed in depth study, using the CBAV method, of students' verbalizations during different type of activities in a virtual laboratory environment.

Concluding the above-discussed observations, we can claim that during a structured lab activity, students express (relatively) less verbalizations about Physics knowledge. On the other hand, in the case of inquiry type activities, students express (relatively) more verbalizations about Physics.

A very interesting result also supported from our data, is that expressions about Physics theory appeared throughout all the activities with 'Thermolab', resulting in a relatively similar Density of verbalization. Given the fact that our background objective was to investigate the linking between theory and practice, we can argue that:

- When students are engaged in virtual laboratory activities using 'Thermolab', in different types of activities there seems to be linking between the world of theory and the world of objects & events
- This linking is much more apparent in the case of inquiry based activities, rather than the case of structured lab activities.

It would be also interesting to compare these results, with the ones reported by Niederrer (2002), while summarizing similar work of other researchers (Buty, 2002; Hucke & Fischer, 2002; Sander, et al., 2002; Theyßen, et al., 2002) that have studied cases of laboratory activities concerning physical objects and computer modeling. Typical results of these studies showed that the manipulation of apparatus and taking of measurements in a traditional laboratory took most of the time (about 50-80%) of labwork, the contribution of these lab contexts to the verbalization of Physics was rather low (lower than 10%).

Within the limitations of this current study, our results indicate that the verbalization of Physics in a virtual Lab environment is found significantly increased (36% and 45% for the two groups in structured lab activities and close to 63% and 58% for the inquiry based activities).

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