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Using SOLO to Evaluate an Educational Virtual Environment in a Technology Education Setting

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ABSTRACT
The present research investigates the contribution of an interactive educational virtual environment on milk pasteurization to the learning outcomes of 40 students in a technical secondary school using SOLO taxonomy. After the interaction with the virtual environment the majority of the students moved to higher hierarchical levels of understanding on the structure and operation of the pasteurization apparatus, the different paths and temperatures of fresh and pasteurized milk, hot and cold water, and the way heat is exchanged. The functional nature knowledge the students constructed, led them to develop physical nature knowledge, knowledge of the relationship between physical and functional nature, and finally process knowledge. The design of the three dimensional virtual environment, its content and the meaningful learning tasks are important for technology knowledge.

Keywords
Virtual reality, Educational virtual environments, Technology education, SOLO taxonomy

Introduction

Technology education constitutes a separate educational sector of the educational system. Generally, by the term Technology Education (TE) we refer to that particular part of the curriculum that is related to the support offered to students in becoming technologically capable, to the identification of the human needs for which technological solutions are required, to the design and manufacture of suitable products, to the evaluation of product quality and potential social and environmental repercussions (De Vries, 1997, 2005; De Vries & Tamir, 1997). Today TE is undergoing an important transformation. The increasing complexity of society has resulted in a shift of interest from the acquisition of manual skills towards the development of mental skills. The curricula of technological studies in developed countries are changing direction and from providing specific knowledge and practicing skills, emphasis is given to the procedures of problem solving, decision making on technological matters and knowledge of the productive processes (DFE, 1993; ITEA, 2000). Technology educators have to bring together scientific, technological and social knowledge (De Vries, 1997).

Information and Communication Technologies (ICT) are considered to be the most powerful tool for the support of the learning process. ICT with their flexibility, adaptability, their capability of being applied at the work place, their good cost-performance ratio, are being used widely in TE as learning tools. From the various technological approaches of ICT, Virtual Reality (VR) is considered to be the most powerful learning tool, because of its unique characteristics that can be summarized as follows (Mikropoulos & Bellou, 2006):

- creation of three dimensional (3D) spatial representations, namely virtual environments
- multisensory channels for user interaction
- immersion of the user in the virtual environments (VEs)
- intuitive interaction through natural manipulations in real time.

The present work proposes the design, development and evaluation of an Educational Virtual Environment (EVE) in TE for the support of the understanding of the milk production processes as a case study, in a technical school of secondary education. The aim of this study is to investigate the contribution of the proposed EVE to the development of the four different types of technological conceptual knowledge, namely knowledge of the physical nature; knowledge of the functional nature; knowledge of the relationship between the physical and the functional nature, and the process knowledge (De Vries, 2005). For the evaluation of knowledge construction after the EVE-supported intervention, the Structure of the Observed Learning Outcomes (SOLO) taxonomy is used (Biggs & Collis, 1982).

Literature Review

Over the last years a number of VR applications have appeared aimed at the support of the educational process in the field of Technology Education. TE includes a vast number of fields of application such as industry, manufacturing, energy, and transportation; therefore the virtual environments concern a wide variety of applications.

Weyrich & Drewes (1999) have developed a desktop VR system for training in the planning and manufacture of model products, without presenting any empirical data. Parkinson & Hudson (2002) report on the training of 14-16 year old students in the manufacture of automobiles using a desktop system, and found some improvement in the generic process of engineering design. Yap et al. (2003) propose an immersive system for training in the development of industrial products. Their results show a reduction in the design time and the design of more precise products. Hashemipour et al. (2009) present a virtual computer integrated manufacturing laboratory for various engineering disciplines. They report on positive students' attitudes and learning outcomes in undergraduate courses. These four applications aim at training in productive processes. The users manufacture virtual products, interact with the virtual environment, compare and improve the products. From the four applications only one is aimed at secondary education and reports some general positive outcomes (Parkinson & Hudson, 2002).

Another direction on using VR in TE is quality control and ergonomics. Crumpton & Harden (1997) report an improvement in labour behaviour in the handling of materials and placement of employees using a desktop VR system. Chung et al. (1999) report on a more rapid implementation of inspecting the thickness of industrial parts with college students in an augmented reality environment. Vora et al. (2002) have found more precise and easier tracking of imperfections compared to multimedia application by training students with an immersive system.

Some articles report on the training of technicians using machine operation simulations in desktop systems. Song (1996) have found improvement in the quality and speed of performing welding activities, while McLachlan and Papaioannou (1999) report a decrease in the training time compared to the traditional methods in robotic welding. Lapointe and Robert (2000) note a greater harvest of timber, lower cost of repair and maintenance of machines in handling forestry machines in wood harvesting. Lin et al. (2002) report less time and errors on an automatic virtual lathe. Finally, Huang and Gau (2003) report on time reduction in handling a self-propelled lifting crane, but state difficulties with the technicians' perception of the 3D environment.

Concerning assembly tasks, understanding of industrial activities and management of productive processes, four desktop applications and one immersive have been found. Bullinger et al. (2000) propose an immersive system for training in assembling and disassembling objects in planning operations, without giving any empirical data. Wittenberg (1995) reports on the reduction in training cost and the improvement in quality of work, Bell & Fogler (1995) on better comprehension of abstract technical concepts in chemical engineering, while Mills & de Araujo (1999) give positive results for the traditional teaching method in the management of nursing units. The three above studies were conducted with employees, out of the educational system. Finally, Fernandes et al. (2003) propose a virtual factory that allows users to navigate and interact with machines and equipment, but they do not present any empirical data.

There are also some desktop VR systems that simulate safety issues in working environments. Squelch (2000) and Filigenzi et al. (2000) simulate mines; Zayas (2001) proposes safety training at a chemical laboratory, Dobson et al. (2001) at a railway station and a nuclear plant. Duffy et al. (2003) present a virtual environment for risk reduction without any empirical data. However, none of the above five studies are in an educational context and they remain at the description of the virtual environments. Only Squelch and Dobson et al. comment on the contribution of the realism of their virtual environments.

Three desktop systems are proposed for the training of civil engineers in structural analysis (Chou et al., 1997), of students in construction technology (Li & Love, 1998) and in CAD and design (Ou et al., 2002). The positive results reported mainly concern attitudes and skills.

Concerning maintenance and repair of industrial equipment there are two desktop systems without empirical data (Kashiwa et al., 1995; Oliveira et al., 2000) and a virtual environment reporting the reduction of the cost of training (Li et al., 2003). Another virtual learning framework for troubleshooting of automotive chassis has been reported by Liang (2009), together with positive learning outcomes coming out from university students.

From the literature above we observe that 17 out of 29 applications do not report on any training results, but simply make proposals for the educational or training process or even the VEs. In the majority of applications where results are presented, they have not been concluded from systematic evaluation but are based on opinions and statements of usually a small sample. In only a few of them a systematic evaluation has been presented (Chung et al., 2002). In most of the applications, the opinions of experts are reported, as well as the demonstration of VEs and general estimations concerning possible benefits that could be gained by the application. Usually they focus on the design and development of original applications rather than on their assessment by the users. Shewchuk et al. (2002) report that from all the applications they studied, in only 10% of them were systematic empirical studies carried out. Moreover, in those applications that were followed by a statistical analysis of the findings, most of them can be characterised by their many deficiencies such as the small number of the sample, the inhomogeneity of the subjects based on age and the industrial experience. Also minimal are the cases in which the sample consists of students in an educational context.

The above problems lead to a decreased reliability in reference to the results and the conclusions of research (Crumpton & Harden, 1997; Mills & de Araujo, 1999; Antonietti et al., 2001). A basic characteristic of the empirical studies is the emphasis given to the processes of training and acquisition of technical skills. The important element of construction of knowledge in reference to concepts, physical magnitudes and phenomena that are involved in the simulated activities are not studied in depth. The ongoing evolution of technology in all fields requires the comprehension of the relevant physical phenomena, before the training in matters of handling and control. It seems that the researchers using ICT and especially VR to support TE do not exploit all the categories of technological knowledge that is structural and functional rules, technical know-how, socio-technical understanding and technological laws (De Vries, 2003). They probably remain with the ‘concepts of technology’ leaving the ‘concepts in technology’ meaning the theoretical concepts that are used in technological activity out of their research interests (De Vries & Tamir, 1997).

Experiments

The subject under study

Based on the bibliographic review, research was conducted at technical educational institutions and industries aimed at choosing the most suitable topic for the development of an EVE in order to use it as a teaching tool in the educational process. The prerequisites for the choice of topic under study were:

- ascertained needs of education and training
- processes difficult or impossible to be presented and taught by other means
- suitable sample regarding the number, educational level and working experience.

Based on the above criteria, the dairy school of Ioannina, Greece was chosen because on one hand its laboratory contains a complete milk production line and on the other hand the students’ profile fits mostly to future technicians, since after their graduation they are employed on the production line.

Initially, a pilot study was conducted as a pre-test to establish the level of students’ understanding before the intervention with the EVE. The sample of this pilot study consisted of 48 students in their 2nd year at the dairy school (25 boys and 13 girls) aged 17 – 22 as well as the six teachers of the school, five agronomists and one mechanical engineer. The research was conducted at the school. In order to determine the specific topic of the EVE, the study aimed at the investigation of students’ ideas in the process of milk production, the determination of the topics in which the students have misconceptions, and the detection of those particular procedures difficult to be taught by traditional means. For the collection of data for the sample of students a closed type questionnaire was chosen, while for the sample of teachers the method of semi-structured interview was used. Table 1 shows the correct answers of the students, concerning terms, definitions and processes in the milk production line.

The findings show that most of the students showed great misunderstanding in questions that referred to integrated processes of the milk production line such as the preparation of the fresh milk, pasteurization and butter production. The students placed the processes in the wrong order or added others irrelevant to the production line. On the contrary, questions that were related to definitions or certain tasks in a more general production process, gave positive results.

Table 1. Students' correct answers (N = 48)

	Question	Frequency	Percentage (%)
1	Matching terms (homogenization, cream separation, pasteurization) with definitions	42	88
2	Putting procedures in milk production line in order	10	21
3	Definition of homogenization	44	92
4	Definition of pasteurization	46	96
5	Physical processes inside the pasteurization apparatus	11	23
6	Process of cream separation	43	90
7	Feta cheese production	42	88
8	Other cheese production	40	83
9	Butter production	25	52

Regarding the teachers' interviews, all the teachers reported that students show great success in definitions and visible productive processes such as making feta cheese. All the teachers also agreed that pasteurization is the process where students have misunderstandings. They also reported that this is a chronic problem, not only presented in this particular sample. The teachers reported that although, apart from their theoretical teaching they made use of other means, still the students faced difficulties in topics that involve knowledge of the functional nature, knowledge of the relationship between physical and functional nature, as well as process knowledge (De Vries, 2005). Pasteurization, that is the application of heat to destroy pathogens in foods, is a process where the theoretical (physical phenomena) and technical (inability to disassemble the system) difficulties cause misunderstandings in the educational process. It seems that although the students possess knowledge of the 'concepts of technology', they need to acquire knowledge on the 'concepts in technology'.

In conclusion, the students' and teachers' findings showed that the biggest problem is located in the process of pasteurization with difficulties in:

- comprehending the construction, the operation and the inner structure of the pasteurization apparatus
- comprehending the physical phenomena that occur during the process inside the pasteurization apparatus (exchange and regaining of heat)
- the knowledge of the correct flow of the different fluids (hot and cold water, hot and cold milk) and the role they play in the related process
- controlling and confronting incorrect procedures during pasteurization.

The above difficulties that students faced, mainly concern the functional nature knowledge, knowledge of the relationship between physical and functional nature, as well as process knowledge. The process of pasteurization is a characteristic example of a topic where the use of VR seems to show its potential. It is a case where information is hidden, there is no possibility of interacting with the process and it cannot be experienced or be conceived by human senses (Sanchez et al., 2000). Thus, pasteurization was chosen as the specific topic of the case study for the investigation of the VR-supported intervention in TE.

As has been shown by the pilot study, the students have the functional nature knowledge as descriptive knowledge. The research axis of the VR-supported intervention is the investigation of its contribution mainly to the three other types of technology knowledge i.e. is the physical nature knowledge, the knowledge of the relationship between physical and functional nature, and the process knowledge.
Specifically, the intervention investigates if students:

a. acquire functional nature knowledge by learning that milk passes through the pasteurization apparatus in order pathogens to be destroyed
b. acquire physical nature knowledge by learning that metal plates contribute to heat exchange
c. construct the knowledge of the relationship between physical and functional nature by learning that the metal plates inside the pasteurization apparatus contribute to heat exchange between fresh, pasteurized milk and water
d. construct process knowledge by learning that pasteurization is the process of destroying pathogens in foods using the application of heat by passing milk through the pasteurization apparatus that contains metal plates for heat exchange between fresh, pasteurized milk and water.

The Educational Virtual Environment

The entire milk production line is simulated and emphasis is given to pasteurization. Particular attention is given to the users' interaction with the virtual objects through free navigation, and the possibility of changing specific variables of the simulated operations. Objects are not designed symbolically but realistically and in correspondence to the real ones. Finally, attention is paid to the attributes of the EVE so as to correspond to the characteristics, the needs of the students and the pedagogical principles of TE.

For the development of the EVE the Superscape VRT software was used. The basic characteristics of the EVE are the 3D representations of the production line equipment at the dairy factory, free and guided navigation and interaction. Specifically:

- The tanks of fresh and pasteurized milk, the cream separator, the constant-level supply tank, the pasteurization apparatus, its inner parts (plates and their cross sections, the hot, cold water pipes and fresh, pasteurized milk pipes and the holding tube of milk) are designed
- The surfaces of the virtual objects are colored so as to be photorealistic. Especially for the pipes and the flow of the fluids, different colors play an important role, as each one symbolizes a different fluid
- Proper textures are used in order to enhance the true likeness of the objects especially in the cases of the pasteurization apparatus and the plates
- An operational and control panel is designed by which the functions of the equipment are controlled. It is placed at the side of the EVE in order to avoid any interference with the students' navigation
- Physical properties are given to the virtual objects such as transparency to the pipes and velocity to the fluids
- The flow of the pasteurized and fresh milk, cold and hot water, the inner part of the pasteurization apparatus, display of temperatures at the appropriate time, case of faulty pasteurization are properly programmed.

The EVE is divided into three levels of operation. The first one includes building the pasteurization apparatus, the second one the various paths of the fluids and the third one the exchange and the regaining of the heat between the fluids as well as the case of faulty pasteurization. The users had the ability to activate any level, according to the operation they wished to study. Figure 1 shows the open pasteurization apparatus and its inner parts (plates and their cross sections, the hot and cold water pipes, fresh and pasteurized milk pipes and the holding tube of milk). Each level of operation begins with a guided navigation, while the choice of free navigation is also activated for free moving and observing of the operations from the users' viewpoints. Before all these actions take place, the user navigates freely in the EVE in order to be familiar with it and to be able to identify the equipment.

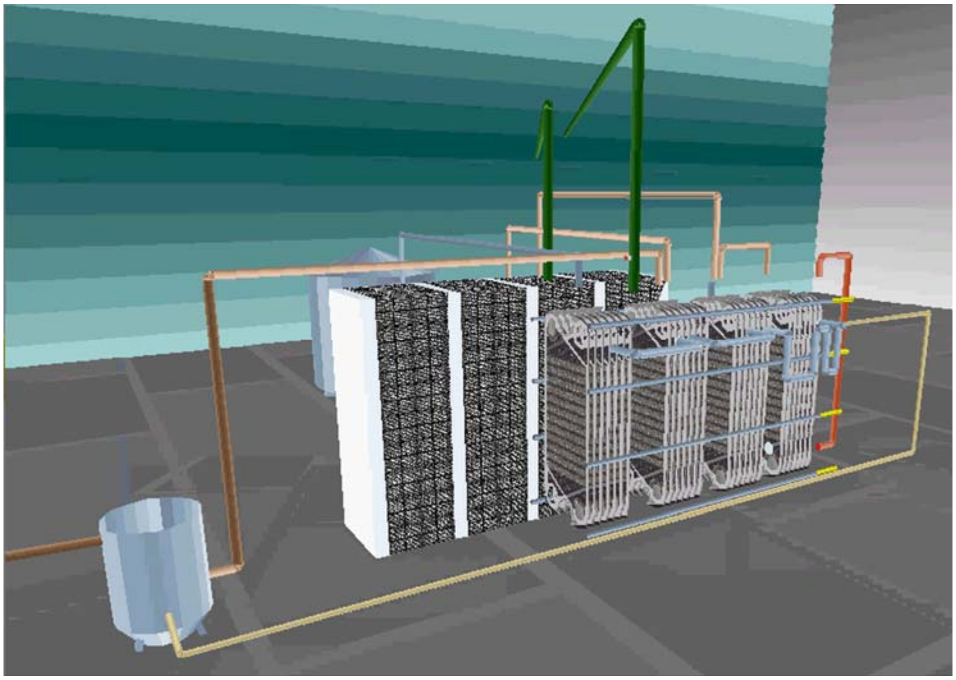

Figure 1. The open pasteurization apparatus and its inner parts

Sample and procedure

The sample consisted of 40 students (others than those of the pilot study) of the dairy school of Ioannina, ages 18 – 22. The students, following their curriculum, attended the lecture given by the traditional method. Just after the lecture, the students were given printed questionnaires with 16 questions related to the taught topic. After that, the students interacted with the EVE. The procedure took place in the computer lab of the school. At the beginning the researcher explained the use of the software and he allowed each student to navigate for a few minutes and become familiar with the EVE. Afterwards there was individualised intervention. After the interaction the students answered the same as before questionnaire. The 16 questions included memorization, comprehension, knowledge construction, analysis and design skills. For the purposes of the present study the findings from five questions are qualitatively analyzed -those that are closely related to knowledge of the physical nature, knowledge of the functional nature, knowledge of the relationship between physical and functional nature, and process knowledge.

After searching relevant references on the suitable tools for qualitative analysis, the SOLO taxonomy was chosen. "In the SOLO taxonomy, the growth of competence is characterized as a shift from accruing the elements of a task in a quantitative fashion, to a qualitative restructuring of the elements and, at the highest level of competence, their subsequent reformulation and generalization" (Biggs, 1996). SOLO provides a systematic way of describing how a learner's performance grows in complexity when mastering many academic tasks. The taxonomy has been widely applied to research for the estimation of knowledge presenting different hierarchy levels expressing the development of knowledge construction. Students' understanding is classified in the following five hierarchical levels:

1. Prestructural. The student avoids or repeats the question, makes an irrelevant association.
2. Unistructural. The student selects one relevant datum and closes on that.
3. Multistructural. The student selects two or more relevant data, uses them inconsistently and reaches an alternative conclusion.
4. Relational. The student uses most or all relevant data, integrates it with a relating concept and reaches the right conclusion.
5. Extended abstract. The student uses abstract principles that show the specific example is just one of many possible results.

SOLO is effective in TE since through its hierarchical levels, the transition from functional and physical nature knowledge to the knowledge of the relationship between them and the process knowledge can be evaluated.

Results and Discussion

Concerning the subjects' prior computer use experience, all of them (N = 40) had more than one year experience in general purpose software applications. The most common use for 28 students was game playing.

The EVE

During their interaction with the EVE, the students were asked to identify six apparatuses that are involved in the production process of pasteurization. From a total of 280 answers, 261 (93%) were positive. Concerning the realism of the virtual objects, the answers were positive. There were 176 answers reporting that the objects resemble the real objects a lot, 46 that they resemble them a little and only eight that there is no resemblance. Most of the students also noted that it was easy to identify the apparatuses not only because of their realistic representations, but also because of their particular place and role in the production line that was simulated. This shows that the students acquired physical nature knowledge during their interaction with the EVE, since they realized that "artifact A has physical property p" (De Vries, 2005). Regarding the ease of navigation in the EVE, 27 students found it very convenient, 11 showed a little difficulty and only two reported great difficulty. The different colors of the pipes which matched the different fluids provided assistance to 37 students, while they confused only three of them.

There was a typical question referring to the sense of the user's presence inside the EVE (Slater, 1999): 'during your navigation in the virtual environment did you feel like you were inside the factory or did you think that pictures of the factory passed in front of you?' Thirty students felt that they were inside the virtual factory while only 10 sensed it as images on the computer screen.

The above results show that the students evaluated the characteristics of the EVE positively and indicate that the EVE contributed to the knowledge of the physical nature. The careful design of the virtual environment is essential to enhance the possibilities of success when it comes to the cognitive area. Our findings enhance those of Yap et al. (2003) reporting that 3D models and simulations can capture dynamic mental visions and concepts of products: 'they not only provide full form geometric representations of objects but also illustrate procedural knowledge (i.e. object functions)'.

SOLO analysis

The prestructural, unistructural, multistructural, and relational hierarchical levels have emerged from the SOLO analysis of the five questions. The last extended abstract level has appeared neither before, nor after the students' interaction with the EVE. We follow De Vries' approach to technological knowledge that is students 'must learn to make judgements about effectiveness … that makes it distinct from scientific knowledge' (2005). So, for technology education we believe that there is no need for the students to use abstract principles that show that the specific example is just one of many possible results.

The five questions are summarized as follows:
Q1: Describe the inner part of the pasteurization apparatus and draw a sketch of it (both physical and process nature knowledge).
Q2: Explain the role of the holding tube pipe (both physical and functional nature knowledge).
Q3: Explain the operation of the constant-level supply tank (knowledge of the relationship between physical and functional nature).
Q4: Explain the way the recuperation of heat is accomplished (knowledge of the relationship between physical and functional nature).
Q5: Explain the way the pasteurization apparatus' plates operate (process knowledge).

Figures 2 and 3 show the SOLO levels before and after students' interaction with the EVE for questions Q1 and Q2 that represent physical nature knowledge.

Concerning Q1, the majority of the students are classified at the first two levels before their interaction with the EVE, while a shift towards multistructural and relational levels is observed after the EVE, leaving only one student at the prestructural level. This great shift indicates the contribution of VR to topics where it is impossible for students to have experiences in the real world. This is enhanced by the correct descriptions concerning the way the plates operate, the explanation regarding the part of the apparatus where the pasteurization process integrates, as well as the part where the milk is finally cooled.

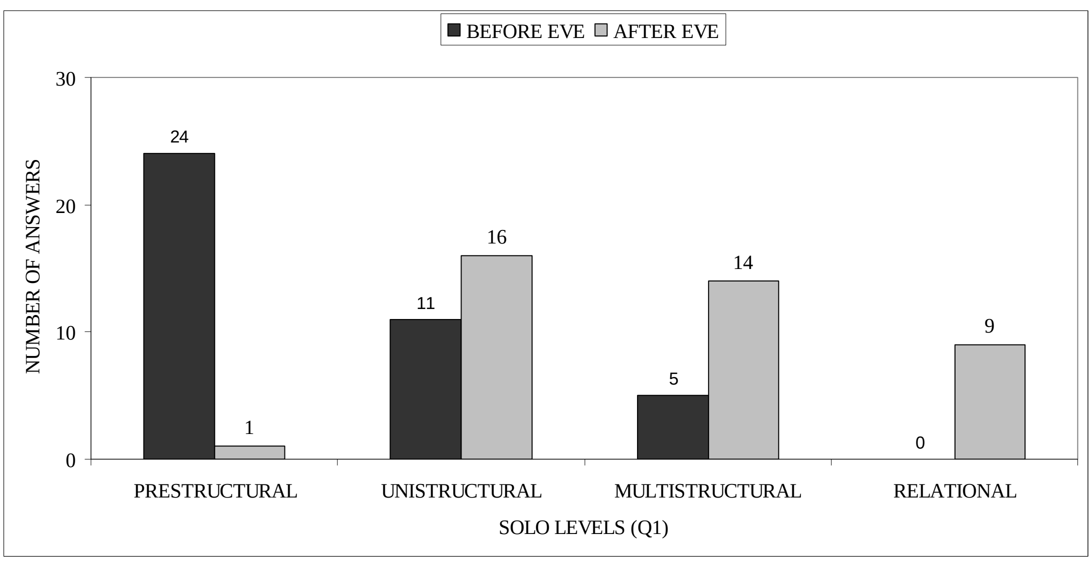

Figure 2. SOLO levels for Q1

The pasteurization apparatus consists of four parts, each one consisting of a series of parallel plates helping the heat exchange in milk. Fresh milk flows through the plates gradually increasing its temperature, with the final part of the pasteurization to be held in the fourth plate. The pasteurized milk is finally cooled in the first plate. The heating process is done by the hot water flowing through the three plates, while the cooling process is done by the cold water in the final stage of the process. After the interaction with the virtual apparatus, 29 students described correctly the paths of cold and hot water inside the plates. The results for the paths of the milk were also improved, with 19 correct descriptions for the fresh milk and 21 for the pasteurized. Although the correct answers for the milk after the EVE are at a satisfactory level, they are considerably less than those for the water circulation. It seems that the role of the water inside the apparatus is clearer to the students than that of the pasteurization process itself. The satisfactory descriptions of the fluids' paths can be associated with the high score for the correct answers concerning the structure of the apparatus. It seems that although the students have understood its structure, they cannot discriminate the exact role of its parts in relation to the four fluids. Apart from the students' descriptions this is also indicated by their sketches that show a polyline representing the fluid pipes before the EVE. After the interaction with the EVE, the sketches represent the four metal plates and the pipes with accuracy.

The same shift towards higher SOLO levels is observed in the role of the holding tube (figure 3), which is located after the fourth plate, controls milk's temperature and certifies the pasteurization. Here most of the students moved to the unistructural and multistructural levels, while five of them returned from multistructural to the unistructural level. It seems that the specific physical nature knowledge requires three different factors, time, temperature and pasteurization where the students have misconceptions that a visual representation cannot overcome.

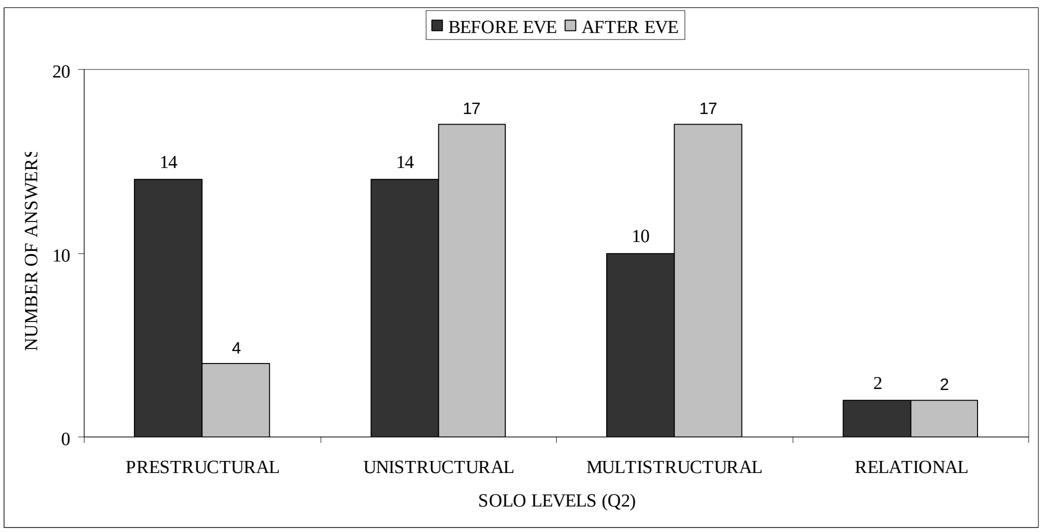

Figure 3. SOLO levels for Q2

Two students' comments follow.
S1, before EVE: "Because the milk is too much, it cannot remain inside the plates; thus, it remains in the holding tube".

The student invents an explanation based on the etymology of the term. The answer is classified at the first, prestructural SOLO level.
S1, after EVE: "Milk stays in the holding tube for 15sec in order for the pasteurization process to be accomplished".

The same student S1 refers to the role of the holding tube and the staying time, but not to the temperature. The answer is classified at the multistructural level, showing a two – level shift.
S2, before EVE: "Milk stays for 15sec".

The student has a descriptive and inert knowledge concerning one of the factors for the role of the holding tube. The answer is at the unistructural level.
S2, after EVE: "Milk stays in the holding tube for 15sec at the correct temperature in order for the pasteurization process to be integrated".

S2 uses and relates all the appropriate factors. The answer is shifted from unistructural to the relational level.

Figure 4 shows the SOLO levels for Q3 concerning the operation of the constant-level supply tank. This is placed before the pasteurization apparatus and ensures the steady flow of the fresh milk. In case of wrong pasteurization, milk returns to the tank and the process starts again. This is considered to be knowledge of the relationship between physical and functional nature. Six students from the prestructural are shifted to higher levels. One of them is classified at the unistructural, while five at the multistructural level after their interaction with the EVE.

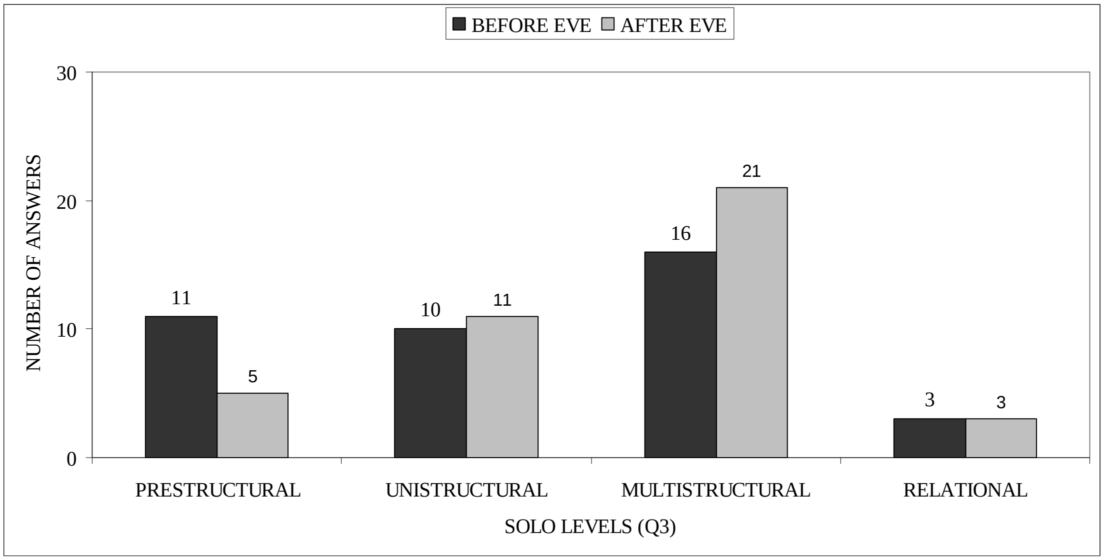

Figure 4. SOLO levels for Q3

Two students' comments follow.
S3, before EVE: "Milk flows from the tank to the pasteurization apparatus".

The student generally refers the place of the tank, but ignores its purpose. The answer is at the unistructural level.
S3, after EVE: "The tank ensures the steady flow of the fresh milk; milk returns to the tank in case of incorrect pasteurization".

S3 knows the operation of the tank, but ignores its location. The answer is shifted to the multistructural level.
S5, before EVE: "The tank is located before the pasteurization apparatus and pumps milk to it".

The student uses only one datum and his answer is at the prestructural level.
S5, after EVE: "The constant-level supply tank ensures the steady flow of the fresh milk; milk returns to the tank in case of incorrect pasteurization".

S5 knows the operation of the tank, but ignores its location. The answer is shifted to the multistructural level.

Figure 5 shows the SOLO levels for Q4 concerning the way the recuperation of heat is accomplished. It is observed that 21 students moved from the first, prestructural to multistructural and relational SOLO levels, showing an understanding of the relationship between physical and functional nature. It is noteworthy that the relational level is occupied by 14 students after their interaction with the EVE, in contrast to only two answers before the interaction.

Some examples of students' comments follow.
S1, before EVE: "Milk passes through the recuperation part. At the same time hot water passes too, and heat exchange is accomplished".

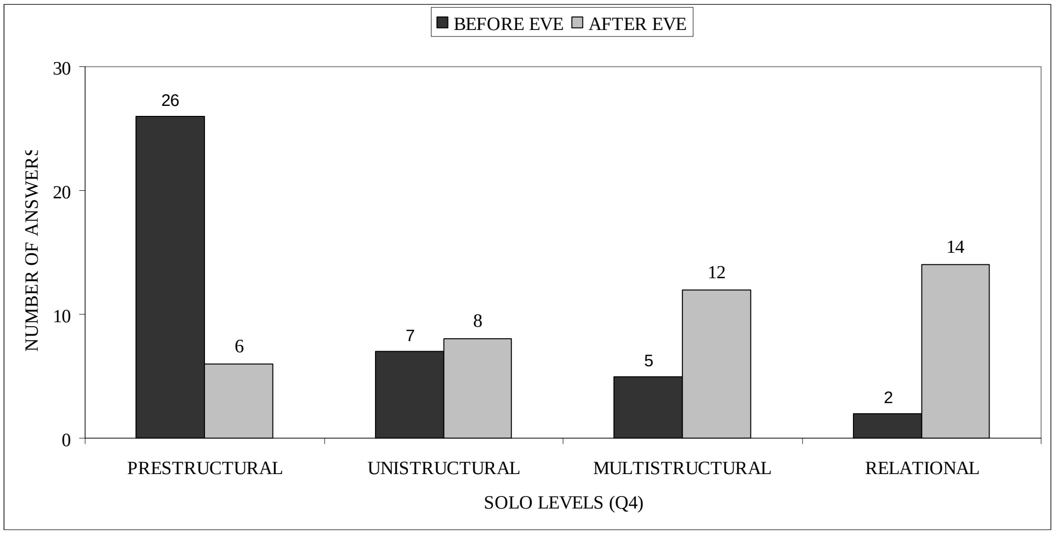

Figure 5. SOLO levels for Q4

The student uses only one datum, that of the milk, but confuses heat recuperation with heat exchange. The answer is at the unistructural level.
S2 and S3, before EVE: No answer.

No answer is at the prestructural level.
S1, S2 and S3, after EVE: "Fresh milk switches with pasteurized milk inside the metal plates and heat recuperation is done".

The three students spot the place where the phenomenon is done and understand the process. Their answers are shifted from unistructural and prestructural to relational level. Question 4 belongs to a high level of technology knowledge that involves a physical phenomenon and a resulting process. The findings show the contribution of the EVE in cases where students have neither previous experience of the system and the process, nor mental models about the phenomenon.

Figure 6 shows the SOLO levels for Q5 concerning the integrated operation of the pasteurization apparatus that is classified as process knowledge. After the interaction with the EVE, students' answers move mainly from prestructural to multistructural and relational levels, indicating together with Q1 a better understanding.

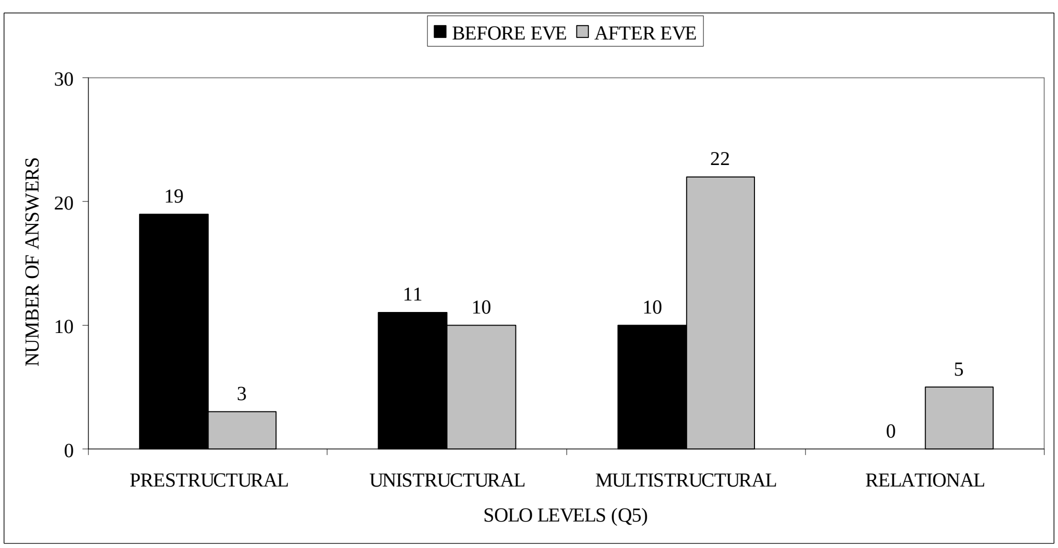

Figure 6. SOLO levels for Q5

Two students' comments follow.
S1, before EVE: "The first plate pasteurizes milk to 75^{o}C, the second heats it to 40^{o}C, the third up to 60^{o}C, and the fourth cools milk at 5^{o}C".

The student confuses plates with the apparatus parts. The same student did not manage to sketch the apparatus. Moreover, he does not know the heating and cooling processes. The answer is at the unistructural level.
S1, after EVE: "The plates are parallel to each other. Cold and hot water, fresh and pasteurized milk pass through them and the processes are integrated".

The student differentiates plates from parts, understands the construction and the operation of the system. His answer shifts to the relational level.
S5, before EVE: "Hot water or water vapour, hot or cold milk is in the heat inverter. Using the ice tank and water, hot milk is cooled".

The answer is general and unclear. The student uses irrelevant data. The answer is at the unistructural level.
S5, after EVE: Same as S1.

The answer shifts from the second to the fourth relational SOLO level.

In order to have a total picture of the students' SOLO levels, we have calculated the average level for each student taking into account the findings of the four above questions (Figure 7).

The students' average hierarchical levels accumulate at the first two levels before their interaction with the EVE. Thirty three students are at the prestructural and unistructural levels, indicating that either they do not understand the questions or their answers are unclear based only on one datum. After the interaction with the EVE there is a shift towards the higher levels with 26 students concentrated at the multistructural level. This shows that the students are able to select more than one relevant data, use them and reach a correct or satisfactory conclusion. The only one classification at the relational level in the total picture comes from the averaging. As one can see from the hierarchical levels for each one of the questions, there are many students classified at this fourth level.

Figure 7. Average SOLO levels

Conclusions

The present study investigated the contribution of an EVE in TE and especially in milk production. The aim was to investigate the contribution of the proposed EVE to the types of technology knowledge that is the functional nature knowledge, the physical nature knowledge, the knowledge of the relationship between physical and functional nature, and the process knowledge. These types of knowledge are detected by analysing 40 students' answers using the SOLO taxonomy that classifies students' understanding at five hierarchical levels.

The results of the students' interaction with the EVE showed a shift from lower to higher SOLO levels, indicating an improvement in students' understanding concerning certain parts of the pasteurization process. Students could conceive unseen processes of production, comprehend complex operations and compose technically acceptable opinions. The qualitative analysis shows in greater detail the changes in technological knowledge after the interaction with the EVE. Specifically the students:

- constructed knowledge and decreased their ambiguities and misconceptions
- were able to compose in a more efficient way concepts and productive procedures
- compared the different parts of equipment with the activities with which they are connected
- developed skills of a superior level essential for the performance of complex tasks
- understood at a satisfactory level the inner part of the pasteurization apparatus and comprehended the processes which they are related to.

Our findings show a greater benefit for students classified at the prestructural and unistructural knowledge level, since the number of questions left undone or totally wrong answers were decreased dramatically. The results of the present study are in accordance with Yap's et al. conclusions stating that spatial, aesthetic, ergonomic, and functional knowledge in 3D visual representations is better communicated by visually observing objects, forms, and processes in motion (2003). Furthermore, our results extend Yap's conclusions, since the interactivity and the sense of presence in our EVE contribute to physical nature knowledge, the knowledge of the relationship between physical and functional nature, and the process knowledge, bringing positive learning outcomes not only to technology knowledge, but also to scientific concepts. It seems that the context and the content of the EVE along with specific learning tasks is an important factor affecting task performance and knowledge construction.

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