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Virtual reality and hypermedia in learning to use a turning lathe

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Abstract A Virtual reality environment with hypermedia was designed to help undergraduates understand the structure and functioning of a turning lathe. Study 1 was carried out with 30 novice students and Study 2 involved 24 students attending a machining course. These studies demonstrated that the virtual lathe can foster the comprehension of some core machining concepts. Further, the studies suggest that novice students benefit most from earlier free navigation of the virtual environment whereas expert students benefit from an analysis of the hypermedia.

Keywords: Comparison; Engineering; Hypermedia; Instruction; Questionnaire; Undergraduate; Virtual reality

Information technologies and engineering instruction

Current needs and Virtual reality

There are many multimedia teaching aids available for machining and manufacturing engineering education. However, the problems currently encountered in the use of such instructional tools account for the computer packages' limited interactivity; for the lack of online assessment of students' competence levels and for the difficulty of integrating the presentation of notions and concepts with an active exploration that the software allows (Day & Suri, 1999). The educational tools designed should allow personalised training and learners' activity should prioritise an immediate evaluation of their individual actions. Thus, the development of didactic frameworks corresponding to students' individual requirements in different teaching contexts is needed (Day & Suri, 1999).

Virtual reality (VR) environments may partially satisfy these needs (Antonietti *et al*. 2000) because they present multiple entry points for personal learning strategies (Traub, 1993) and offer didactic paths that privilege an intuitive approach (Helsel, 1992). Moreover, VR helps students to learn in a natural, perceptual-motor learning way (Ferrington & Loge, 1992). When students are working in a VR environment, they can receive immediate feedback about the relevance of their actions because they can see at once if the desired goal is achieved or if it is actually possible to perform the planned actions. Further, VR clarifies some implicit assumptions underlying concepts to be learned (Antonietti & Cantoia, 2000). Also, upgrading a VR machine can be fast so that schools can have the latest technology and students can work on machines which are currently in real use (Osberg, 1995).

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Integration of Virtual reality and hypermedia

VR alone, however, is not sufficient. Students must be able to make sense of the controls (e.g. levers, knobs, switches) of the machine in order to make use of the virtual machine. To do this, specific notions and concepts about the machine structure and functioning are required. Hypermedia seems to be the best tool to provide students with this kind of knowledge. In fact, hypermedia permits textual and visual information to be presented together and this should be particularly beneficial in engineering instruction. Training in procedures may be a case to include animated graphics in texts since the actions or their consequences may be difficult to describe verbally. Furthermore, graphics could present textual content in a different format which encourages learners to adopt a different perspective on that material. This change of viewpoint may promote useful cognitive activity. These advantages, however, should not lead one to forget that the inclusion of visual materials in a text may lead to text-picture integration problems (Wright, 1991; Van Oostendorp & De Mul, 1996).

A second reason for integrating VR and hypermedia lies in the opportunity to provide notions and concepts during the virtual experience when students see their relevance to the problems they encounter in a concrete task. In fact the nonlinear structure of hypermedia offers direct access to autonomous units of information which need not be acquired sequentially in solving the problem at hand (Shin *et al.* 1994). So, learners can find what they are looking for, even though disorientation effects may occur (Kim & Hirtle, 1995; McDonald & Stevenson, 1996).

A mental model framework

In engineering instruction the integration of VR and hypermedia should help students construct adequate mental models of the machines whose architecture and functioning have to be learned (Kieras & Bovair, 1984). The original meaning of 'mental model' (Johnson-Laird, 1983) refers to an internal representation constituted by a finite number of tokens and by a set of relationships between them. The structure of a mental model mirrors the structure of the corresponding entities in the external world since a mental model is an analogical representation, which preserves the spatial, temporal, cinematic and dynamic properties of the elements it refers to. In other words, there is an isomorphism between the represented tokens and their relationships and the real objects and their relationships. Due to such an isomorphism, operations applied to a mental model produce, in the mental model itself, effects similar to those produced by the parallel operations applied to the real objects. This allows individuals to draw inferences and to predict the actual behaviour of the real elements on the basis of transformations and anticipations carried out mentally on the corresponding model.

This perspective, successfully adopted in various instructional domains (Gentner & Stevens, 1983), seems to be relevant to many topics of engineering education (Kieras & Bovair, 1984). In fact, the core ideas of mental model theory fit well the contents to be learned in this field. For example, machines can be easily conceptualised as set of tokens linked to each other by spatial, temporal, cinematic, dynamic, physical, causal relationships; the understanding of the architecture of a machine involves the comprehension of such a system of relations; the ability to use a machine requires the capacity to operate on its mental structure in order to find out the outcomes of the actions to be applied to the parts of the machine.

The virtual lathe prototype

Structure of the prototype

A prototype to teach the use of the manual centred lathe (Boer *et al*., 1997) through a desktop VR-hypermedia integrated system was designed. It consists of two main environments (VR and hypermedia), plus a third environment (tutor) which has the function of introducing students to the system and of allowing them to choose among some alternatives according to the preferred type of exercise and learning mode.

The prototypal system was built on a personal computer (Pentium processor, 32MB RAM) using VRT 4–00 Superscape for the implementation of the virtual environment and Multimedia Toolbook 4.00 for the hypermedia and tutor .

The *virtual lathe* (Fig. 1) comprises a set of components (structures, piece supports, parts for the information transfer, and control) that receive power, data and materials with the goal of modifying their physical characteristic by a sequence of operations. The machine presents some components that are in relative motion and therefore it is necessary to define their own kinetics characteristics and the synchronisation of their movement according to the specific operation to be carried out. A set of technological parameters comes into play; these, if correctly fixed and linked, allow the goal to be reached. A typical use of the virtual lathe involves the following steps. First the lathe has to be prepared with the necessary accessories: learners have to choose what (for example, the cutting tool) they need from the virtual store and they have to set up the lathe. The set-up must follow a precise sequence of operations (for example, it is not possible to place the working piece on the lathe before positioning the self-centred chuck). Then the necessary parameters, like power and cutting speed, have to be set. Once the lathe is ready to use, the student has to turn the power on and perform the assigned task.

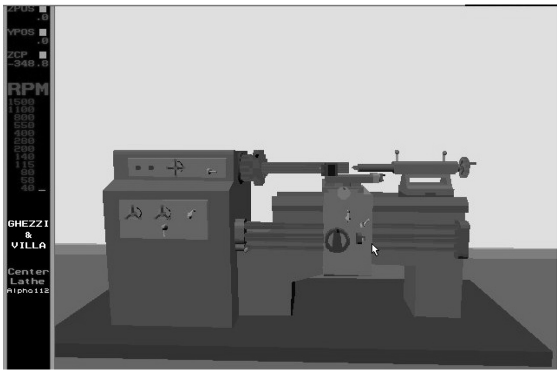

Fig.1. The virtual lathe.

The *hypermedia environment* (see Fig. 2) represents the ‘knowledge manager’ of the system. It allows students to learn through texts, pictures, movies, graphical simulations and VR or real situation demos. It is divided into three parts: glossary, hypertext and simulation. Students can access the hypermedia environment on request; the structure of the student–computer interaction is open-ended. Five different kinds of lesson are implemented: theoretical, demonstration, guided

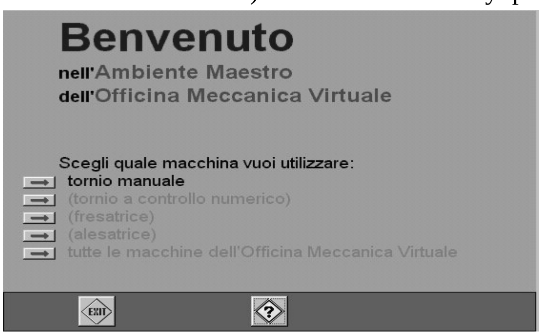

Fig. 2. The hypermedia environment

practice, free practice and examination. Students are allowed to choose the kind of lesson and change it at any time. *Theoretical lesson* works only in the hypermedia environment: the system explains the information related to the chosen issue. In the same environment the *demonstration lesson* is available; it consists of demos related to the chosen manufacturing cycle. In *guided practice* the student performs the operational cycle step-by-step under suggestions and control of the system. In *free practice* students perform the chosen task in the VR environment and can take information from the hypertext environment. The system shows the results at the end of the job or stops the lesson if mistakes occur. Finally, the *examination lesson* consists of a set of questions and practical tasks to be carried without access to the hypermedia environment.

Instructional issues

In engineering teaching through information technologies, both VR experience and hypertextual knowledge acquisition could lead students to construct an appropriate mental model of the machines they need to understand. This was the goal of the prototypal computer-supported system studied in this paper.

The VR environment was designed to enable students to learn about the architecture of the machine (declarative knowledge) and its use (procedural knowledge) within a realistic situation, performing practical operations, both physical (i.e. piece positioning on machine tool and cutting tool movement) and conceptual (i.e. choice of cutting tool from the virtual store, choice of cutting speed). The virtual machine was designed to satisfy several requirements. It is highly interactive because it can work only if students perform the appropriate operations; each operation is followed by feedback. Further, online assessment and direct evaluation are provided because comments about each step of the procedure are given. Comments consist of either error messages and hints (by consulting the relevant section of the hypermedia) or prompts to carry out the next operation. Learning paths are personalised as students are free to operate the machine according to different working styles and they are allowed to begin from an exploration of the virtual prototype or from navigation of hypermedia.

The hypermedia includes only visual information closely related to the text and is focused on specific issues about the lathe structure and its functioning avoiding some of the problems of this environment (Dillon, 1996). Information is presented as a display in which it is easy to match and integrate textual and visual elements (always simultaneously available). The hypermedia tries to reduce possible confusions and disorientation problems by presenting restricted information and providing a map of the whole structure of the environment.

A pilot study was carried out to verify whether novice students (those attending a humanities courses) and experts (those attending technological courses) could benefit from the virtual lathe system (Antonietti *et al*., 1998a; Antonietti *et al*., 1998b). Learning outcomes were evaluated by asking students some questions and by asking them to carry out operations on the virtual machine.

Study 1

Introduction

The pilot study suggested that the virtual machine may enable students to learn what a lathe is and how it works. The next step was to explore in a systematic way the efficacy of the virtual lathe as a tool for machining and manufacturing engineering instruction and to identify the best procedure to train students.

As far as the second issue was concerned, a critical question was: is it better for students to begin by using the virtual lathe or by exploring the hypermedia? The tutor environment allows for either approach. In the first case learning proceeds from action to conceptualisation; in the second case from conceptualisation to action.

The first and the second approach have advantages and disadvantages. The free experience with the virtual tool immediately gives students an overall idea of the machine and this might help them to make sense of the instructions provided by the hypermedia. However, students might spend a lot of time trying to understand how to make the lathe to work and some misconceptions might be induced by incorrect use. On the other hand, the early analysis of the hypermedia should permit students to acquire precise notions about the lathe so that they can operate the virtual machine appropriately. However, knowledge furnished by the hypermedia might be difficult to be 'converted' into adequate actions to be performed on the machine. Which approach actually produces the best learning outcomes? This was the goal of the research reported in this paper.

Method

Thirty humanities undergraduates (ranging in age between 20 and 26 years) voluntarily participated in the Study. They were randomly assigned to one of the following conditions (10 students for each group):

- *VR – Lathe:* participants freely navigated the virtual lathe before looking at the hypermedia;
- *VR – Neutral:* before looking at hypermedia, participants navigated a virtual environment (a room) with no connection to the lathe;
- *Hypermedia:*\participants inspected hypermedia about the lathe without previously having navigated the virtual environment.

Students were given the following questionnaires.

The computer using skills questionnaire asked students to rate on a series of Likert-scales their knowledge and previous experience with educational software; abilities concerning computer use were assessed through self-evaluation. The questionnaire consisted of 16 items. Items concerned the habits and the capacities both to operate on the computer devices and to use autonomously CD-Roms, Internet, spreadsheets, statistical packages, and so on.

The questionnaire about the representation of the lathe consisted of two parts. The first part included eight general questions asking students: to describe a lathe (what it is and how it is arranged), to list its main parts, to say what it is for, to explain how it works, to list the kinds of manufactured goods for which it can be employed, to explain why it may be dangerous, and to figure out which abilities are requested to use it. The second part included four specific questions. The questionnaire was administered twice in the Hypermedia condition or three times in the VR condition. In the first administration only the first part was presented (since students, with no training about the lathe, completely lacked the relevant knowledge to answer the specific questions of the second part). In the subsequent administrations both the first and second part were given. To reduce the mental load on the participants and to avoid too long a session produced decrease of attention and commitment, three items of the first part were omitted as they were redundant.

The questionnaire about hypermedia information consisted of four open questions about specific aspects of the structure and functioning of the lathe. Questions concerned the set-up of the lathe (for example: ‘Which is the position of the self-centring chuck?’; ‘What is the cutting-too for?’).

About 5 minutes were needed to complete the first questionnaire and about 10 minutes for the second and third ones. The students were required to carry out the following operations during the experiment.

- *Free navigation of the virtual environment*: basic instructions for navigation were provided; then students were trained in exploring the virtual environment by allowing them to navigate *ad libitum* the VR prototype (time duration of the task: 15 minutes).
- *Experience with hypermedia*: students were given basic instructions about hypermedia navigation and then they navigated the lathe hypermedia in order to achieve competence to carry out the set up of the lathe (time: 15 minutes).
- *Set up of the lathe in the virtual environment*: students set up the virtual machine. The task lasted 15 minutes. Students’ behaviour was observed and categorised.

The sequences of tasks for each group are reported in Table 1. At the beginning of the experiment students were told that they should be involved in an investigation aimed at studying people’s use of IT in education. During the experiment students should try to learn what a turning lathe is and how it works. They should take advantage of all the sources of information available. In this way all students — both those who began to browse the hypermedia and those who began to navigate the VR environment — were given a solid reason for using all instructional tools which were available. The students were individually observed in the multimedia laboratory during a session of about one hour and half.

Results

Computer use skills Responses given to the *Computer using skills questionnaire* showed that familiarity and ability levels about computer and educational packages were equally distributed among the three groups of participants (see Table 2).

Knowledge about the lathe Initial knowledge about lathes was similar in the three groups, as shown by the analysis of responses given in the 1st administration of the *Questionnaire about the representation of the lathe* and by the responses given at the beginning of the experiment when students were asked to rate on a 4-point scale (4 = minimum; 1 = maximum) both their *abstract and practical* knowledge of the lathe. As far as the last questions were concerned, no significant differences among means under the three conditions were found (respectively, $F_{2,27} = 0.25$ and $F_{2,27} = 0.95$):

- VR Lathe: abstract = 3.60, *sd* = 0.70, practical = 4.00, *sd* = 0;
- VR Neutral: abstract = 3.60, *sd* = 0.70, practical = 3.90, *sd* = 0.32;
- Hypermedia: abstract = 3.78, *sd* = 0.44, practical = 4.00, *sd* = 0

Knowledge presented through hypermedia was acquired by the three groups to the same extent. Responses given to the *Questionnaire about hypermedia information* were converted into scores: 0 (completely wrong); 0.5 (partially right); 1 (completely right). No significant differences among the three groups of learners with respect to each item of the questionnaire and to the mean scores (obtained by summing up scores in each item and by dividing the resulting sum by the number of the items) emerged (mean total scores: VR Lathe = 0.94, *sd* = 0.21; VR Neutral = 0.63, *sd* = 0.23; Hypermedia = 0.85, *sd* = 0.12; $F_{2,27}$ = 0.88).

Table 1. Sequences of the tasks under the different conditions of Study 1 and Study 2.

Study 1		
VR - Lathe condition	**VR – Neutral condition**	**Hypermedia condition**
Computer using skills questionnaire	Computer using skills questionnaire	Computer using skills questionnaire
Questionnaire about the representation of the lathe (1st administration)	Questionnaire about the representation of the lathe (1st administration)	Questionnaire about the representation of the lathe (1st administration)
Free navigation of the virtual lathe	Free navigation of the virtual room	
Questionnaire about the representation of the lathe (2nd administration)	Questionnaire about the representation of the lathe (2nd administration)	
Experience with hypermedia	Experience with hypermedia	Experience with hypermedia
Questionnaire about hypermedia information	Questionnaire about hypermedia information	Questionnaire about hypermedia information
Set up of the lathe in the virtual environment	Set up of the lathe in the virtual environment	Set up of the lathe in the virtual environment
Questionnaire about the representation of the lathe (3rd administration)	Questionnaire about the representation of the lathe (3rd administration)	Questionnaire about the representation of the lathe (2nd administration)

Study 2	
VR-first condition	**Hypertext-first condition**
Questionnaire about the representation of the lathe (1st administration)	Questionnaire about the representation of the lathe (1st administration)
Free navigation of the virtual lathe	Inspecting the hypermedia summary
Inspecting the hypermedia summary	Free navigation of the virtual lathe
Questionnaire about the summary	Questionnaire about the summary
Given task to be performed with the virtual lathe (cylindrical turning)	Given task to be performed with the virtual lathe (cylindrical turning)
Questionnaire about the representation of the lathe (2nd administration)	Questionnaire about the representation of the lathe (2nd administration)

The experimenter recorded time spent in carrying out the task, the number of steps of the procedure followed, and the number of moves employed: no significant differences emerged in any of these measures under the three conditions (respectively, $F_{2,27}$ = 1.12, 0.34, and 0.75). The observer also classified, by considering the sequence of the moves, the strategy by which students achieved the goal: trial-and-error (student's behaviour seemed to be driven by no precise plans), systematic (participant went ahead to work on a different part of the system only when all the relevant elements of the previous part had been adequately set up), or parallel (student operated simultaneously on different parts of the system). The distribution of the frequencies of each kind of strategy followed in each group of participants revealed a lack of significant (χ^2 (4 *n* = 30) = 0.85) strategy–condition associations. Observation was also aimed at verifying that each student succeeded in carrying out the task: this occurred in all cases.

Effects of training Responses given to the *Questionnaire about the representation of the lathe* were converted into scores using the same criteria as in the previous questionnaire.

Table 2. Mean scores and *sd* in the *Computer using skills questionnaire* of Study 1.

	VR-Lathe condition		**VR-Neutral condition**		**Hypermedia condition**		**Whole sample**	
	mean	*sd*	*mean*	*sd*	*mean*	*sd*	*mean*	*sd*
Overall use frequency	2.4	1.50	2.2	1.20	2.2	1.80	2.3	1.50
Game playing	0.8	0.42	0.7	0.48	0.6	0.52	0.7	0.47
Word processing	0.9	0.32	0.9	0.32	0.7	0.48	0.8	0.38
Email	0.5	0.53	0.4	0.52	0.4	0.52	0.4	0.50
Research	0.4	0.52	0.3	0.48	0.2	0.42	0.3	0.47
Accounting	0.2	0.42	0.3	0.48	0.0	0.00	0.2	0.38
Drawing	0.0	0.00	0.2	0.42	0.1	0.32	0.1	0.30
Study	0.1	0.32	0.0	0.00	0.3	0.48	0.1	0.35
Culture	0.2	0.42	0.3	0.48	0.3	0.48	0.3	0.45
Mouse use	2.6	1.17	2.3	0.95	1.6	1.07	2.2	1.12
Hardware problem resolution	4.3	0.67	3.7	0.95	2.6	1.65	3.5	1.33
Browsing	4.0	0.94	3.5	1.43	2.7	1.95	3.4	1.50
Keyboard use	2.8	0.92	2.3	1.06	1.4	0.97	2.2	1.12
Impasse resolution	4.0	0.94	3.5	0.85	2.8	1.62	3.4	1.25
Videogame playing	3.3	1.06	2.7	1.34	2.3	1.70	2.8	1.41
Joystick use	4.2	1.03	3.7	1.70	2.8	2.10	3.6	1.72

Mean total scores in the first and final administration of the questionnaire (5 general + 4 specific items) are reported in Table 3. A significant increase between the first and final administration was found ($F_{1,27} = 78.27$, $P < 0.001$), though there was no significant differences among groups ($F_{2,27} = 2.75$) nor did a significant interaction emerge ($F_{2,27} = 0.10$).

Table 3. Mean scores *sd* in the 1st and final administration of the *Questionnaire about the representation of the lathe* (total score) in Study 1.

Condition	**1st Administration**		**Final Administration**	
	mean	*sd*	*mean*	*sd*
VR Lathe	0.23	(0.30)	0.61	(0.25)
VR Neutral	0.11	(0.18)	0.46	(0.21)
Hypermedia	0.03	(0.06)	0.37	(0.50)

However, it can be seen that the highest improvements occurred in the VR Lathe condition. This trend is evident in Table 4 which reports final performances in the specific questions: at the end the VR Lathe students showed a better conception of the lathe than VR Neutral and Hypermedia students.

Table 4. Mean scores (*sd* in parentheses) in the final administration of the *Questionnaire about the representation of the lathe* (specific questions) in Study 1.

Question	**VR Lathe**	**VR Neutral**	**Hypermedia**
Which is the position of the self-centring chuck?	0.70 (0.48)	0.60 (0.52)	0.20 (0.42)
Which is the position of the built-up edge?	0.40 (0.32)	0.15 (0.20)	0.15 (0.23)
What is the cutting-tool for?	0.45 (0.41)	0.10 (0.30)	0.10 (0.23)
Which are the elements to pay attention to while using a lathe?	0.70 (0.48)	0.40 (0.32)	0.50 (0.53)
Total	**0.56 (0.34)**	**0.31 (0.44)**	**0.24 (0.41)**

It is worth noticing that after the free navigation of the virtual environment, VR Lathe students learned some concepts about the lathe, as Table 5 shows with respect to the 5 general questions which were common to the 1st and 2nd administration of the questionnaire.

Table 5. Mean scores (*sd* in parentheses) for the *Questionnaire about the representation of the lathe* (general questions) in the VR Lathe condition in Study 1.

Question	**Before navigation**		**After navigation**	
	mean	*sd*	*mean*	*sd*
What is a lathe?	0.20	(0.05)	0.90	(0.17)
How is a lathe arranged?	0.20	(0.11)	0.70	(0.21)
Which are the main parts of a lathe?	0.10	(0.09)	0.35	(0.12)
How does a lathe work?	0.20	(0.13)	0.40	(0.20)
Why may lathe using be dangerous?	0.20	(0.11)	0.60	(0.28)
Total	**0.18**	**(0.17)**	**0.59**	**(0.30)**

Conclusion

The Study demonstrated that novice students (as humanities undergraduates were) did not encounter difficulties in understanding the core concepts of the structure and functioning of a lathe even though some errors occurred. In fact, performance in the final administration of the *Questionnaire about the representation of the lathe* was far from the highest possible levels. This was evident in some specific items of the questionnaire, such as for instance, those concerning the correct position of the built-up edge or the right use of the cutting-tool (see Table 4). Presumably, whereas experience with the virtual system was enough to yield an overall understanding of the machine, such an experience did not induce more sophisticated learning outcomes, closely linked to a technical terminology. However, it is encouraging that even a short experience with hypermedia information and with the virtual prototype allowed students to improve their knowledge and comprehension of the lathe. As far as this issue is concerned, results suggested — even though only a trend and not statistically significant effects emerged — that the best procedure is to let students navigate freely using the virtual tool before presenting hypertextual information.

The increases in the competence recorded in the VR Lathe condition as compared to the Hypermedia condition did not depend on the fact that in the last condition the *Questionnaire about the representation of the lathe* was administered only twice, instead of three times: in fact, performance in this condition was not significantly different from those in the VR Neutral condition where such a questionnaire was administered three times. Further, the higher levels of competence recorded at the end of the experience in the VR Lathe condition did not depend on the fact that students in this condition had a longer training period or that during the free navigation of the VR environment they learned how to navigate and then (when they were requested to set up the virtual lathe) took advantage of such learning because in this phase they did not have to focus their attention on the navigation devices but could draw attention exclusively to the features of virtual machine. In fact, the overall duration of the training was the same for the VR Lathe as for the VR Neutral group so that both groups might have benefited from the free navigation of the VR environment. However, only the VR Lathe group, but not the VR Neutral group, improved performance to a remarkable extent in comparison to the Hypermedia group. Thus, it seems that the initial free experience with the virtual tool had a selective effect in helping students to understand the lathe. In contrast, the possibility that the lower rate of responses in Hypermedia students depended on learning time (which was shorter in this condition as compared to the VR Lathe condition) cannot be discounted. In any case, the trend recorded indicated that learning from hypermedia is enhanced if it is preceded by a VR experience.

Study 2

Introduction

Study 1 showed that novice students can use the virtual lathe and can learn something about its structure and use. However, it was expected that the best learning outcomes could be obtained by using this instructional tool in its natural setting, namely, in an engineering course about machining. The goal of Study 2 was to assess the efficacy of the virtual lathe in such a context. This case also compared two instructional procedures in which the order of presentation of virtual navigation and hypermedia was changed. The rationale for this comparison was the same as in Study 1: the aim was to assess empirically whether the richest mental model of the lathe is prompted by action-conceptualisation or by a conceptualisation-action learning approach.

Method

Participants (age: 20–26 years) were recruited from a technical course about machining. After a short oral presentation, the *Questionnaire about the representation of the lathe* was given. The questionnaire included seven general items (the five questions presented in the final administration of the same questionnaire in Study 1, a question concerning abilities of using a lathe and a question about cylindrical turning and four specific items. All students attending the course (n = 40) filled in the questionnaire. As in Study 1, the initial administration of the *Questionnaire about the representation of the lathe* was preceded by two questions, asking to rate on a 4-point scale, abstract and practical competence about the lathe. Afterwards, the teacher began to explain the unit about the lathe by following a traditional educational approach (a 2-hour lecture). At the end of this unit, students were asked to volunteer for training to be held in a VR environment. Twenty-four students participated in this phase of the Study. They were individually studied during a one-hour session.

In this session two main learning tools were presented: a hypermedia summary of the core concepts and the virtual lathe used in the previous investigation. To verify whether the content of the summary had been acquired, a specific questionnaire was devised: students were asked to draw a lathe and to list the main parts and to explain their functions. Then, since participants were not naive students, during the main experience with the virtual lathe they were requested to perform a more complex task (cylindrical turning) than the set up of the machine. Finally, students filled in the same version of the *Questionnaire about the representation of the lathe* administered at the beginning of the experiment.

Participants were randomly divided into two equal groups of 12 individuals. According to the group, the sequence of the tasks was as reported in Table 1. Ten minutes were allowed for the free navigation and 15 minutes for the cylindrical turning; 10 minutes were allowed to inspect the summary; 10 minutes were allowed to fill in each questionnaire.

Results

Knowledge about the lathe Responses initially given to the *Questionnaire about the representation of the lathe* were scored as in Study 1. Students who subsequently participated to the virtual environment training did not differ significantly from students who did not participate (mean total score of the participants = 0.53, *sd* = 0.24; mean total score of the non-participants = 0.60, *sd* = 0.31; $F_{1,22}$ = 1.20). Thus, is appears that participants were representative of all students attending the course. It is worth noticing that the Study 2 participants, who were technical students, revealed higher initial competence regarding the representation of the lathe than novice students participating in Study 1 (comparison between Table 5, first column, and Table 7, first and third columns).

Focussing on the participants, it can be seen that at the beginning students assigned to the VR-first and to the Hypermedia-first conditions had a similar knowledge of the lathe. In fact both in the two preliminary questions and in the specific items of the *Questionnaire about the representation of the lathe,* no significant differences between the two conditions were found (Table 6).

In the *Questionnaire about the summary* Hypermedia-first students performed better than VR-first students: the first group listed and explained a mean number of lathe elements (respectively 8.42, *sd* = 2.75, and 6.50, *sd* = 2.24) higher than the second group (respectively, 7.08, *sd* = 3.06, and 5.67, *sd* = 2.42). So, even though statistical analyses failed to support the existence of significant differences (respectively, $F_{1,22}$ = 1.26 and $F_{1,22}$ = 0.77), it seems that information provided by hypermedia was better assimilated when it was presented before the exploration of the virtual environment. Recent effects on memory can be discounted because, in the VR-first, but not in the Hypermedia-first case, inspecting the summary immediately preceded the administration of the corresponding questionnaire.

Table 6. Mean scores (*sd* in parentheses) for the *Questionnaire about the representation of the lathe* (preliminary ratings and specific questions) under the two conditions of Study 2.

Question	**VR first**	**Hypermedia first**	**ANOVA $F_{1,22}$**
Abstract competence	2.58 (1.00)	3.08 (0.67)	2.08 n.s.
Practical competence	3.08 (1.00)	3.67 (0.78)	2.55 n.s.
Which kinds of turning does the lathe allow to perform?	0.67 (0.33)	0.58 (0.19)	0.58 n.s.
Does the size of the object to be worked affect the set up of the lathe?	0.58 (0.19)	0.50 (0.21)	1.00 n.s.
Which are the main cutting movements involved in the ? cylindrical turning	0.29 (0.26)	0.33 (0.25)	0.16 n.s.
Which kinds of objects does the lathe allow to work?	0.54 (0.26)	0.58 (0.19)	0.20 n.s.
Total	**0.52 (0.16)**	**0.50 (0.19)**	**1.76 n.s.**

Effects of the training The training with the virtual tool improved students' understanding of the lathe, as shown in Table 7 which gives mean scores in the general items of the *Questionnaire about the representation of the lathe* and scores obtained by summing up scores in such questions and by dividing the sum by the number of the items. In most cases a significant effect due to the phase (1st vs. 2nd administration) was found: after training both groups enhanced performance in comparison to the initial levels. Indeed, as revealed by the analysis of individual protocols, only two participants (one in the VR-first and one in the Hypermedia-first condition) did not increase their knowledge. It is interesting that significant improvements due to the phase failed to emerge in the two last questions, which were not concerned with notions about the machinery of the lathe, that is, with the direct goals of the instructional tool.

Table 7. Mean scores (*sd* in parentheses) for the *Questionnaire about the representation of the lathe* (general questions) under the two conditions of Study 2.

Question	VR-first		Hypertext-first		ANOVA effects		
	1st Admin	2nd Admin	1st Admin	2nd Admin	Group ($F_{1\ 22}$)	Phase ($F_{1\ 22}$)	Group X Phase ($F_{1,22}$)
What is a lathe?	0.75 (0.40)	1.00 (0.00)	0.75 (0.26)	1.00 (0.00)	0.00 n.s.	13.20 ***	0.00 n.s.
How is a lathe arranged?	0.58 (0.47)	0.87 (0.31)	0.54 (0.33)	1.00 (0.00)	0.15 n.s.	21.47 ***	1.06 n.s.
Which are the main parts of the lathe?	0.58 (0.29)	1.00 (0.00)	0.46 (0.26)	0.94 (0.17)	3.96 n.s.	39.39 ***	0.00 n.s.
How does the lathe work?	0.42 (0.36)	0.87 (0.23)	0.46 (0.26)	0.92 (0.19)	0.33 n.s.	32.07 ***	0.00 n.s.
Which is the right procedure to set up the lathe to lathe to perform a cylindrical turning?	0.46 (0.40)	0.87 (0.23)	0.29 (0.26)	0.96 (0.14)	0.23 n.s.	59.97 ***	3.19 n.s.
Which are the elements to pay attention to while using the lathe?	0.50 (0.00)	0.46 (0.14)	0.46 (0.14)	0.50 (0.00)	0.00 n.s.	0.00 n.s.	2.00 n.s.
Which abilities are needed to use the lathe?	0.50 (0.00)	0.36 (0.23)	0.25 (0.25)	0.46 (0.14)	2.05 n.s.	0.71 n.s.	11.35 **
Total	**0.54 (0.21)**	**0.78 (0.34)**	**0.46 (0.19)**	**0.83 (0.42)**	**1.06 n.s.**	**32.98** ***	**0.21 n.s.**

** $p < 0.01$ *** $p < 0.001$

Conclusion

Study 2 also revealed that students attending machining courses within an engineering faculty benefited from the experience with the virtual lathe. Significant improvements between the initial and final phase of the experiment were found in the representation of the architecture and functioning of the turning lathe.

As far as the comparison between the two instructional procedures were concerned, in the sample of learners who participated in Study 2 a trend was observed, which was different from that recorded in Study 1. In Study 2, in fact, the highest increase in competence occurred in the Hypermedia-first rather than in the VR-first condition. Thus it seems that for expert students it is more effective to acquire conceptual notions first (thanks to the hypermedia) and then to apply them to the virtual machine, instead of the opposite sequence.

Discussion

The two studies carried out showed that the virtual lathe can be used to teach what a lathe is and how such a machine works. The integration of VR and hypermedia allowed students to understand the essential features of the lathe and to update or to restructure their initial cognitive representation of the machine. Also, trends recorded in Study 1 suggested that novice students' learning is enhanced when the exploration of the virtual lathe precedes the presentation of hypermedia information. Conversely, as supported by the results of Study 2, for expert students it is better to begin to explore the hypermedia and then to navigate the virtual environment.

Presumably in the first case, students lacked any idea about the lathe. Thus, the concrete experience provided by the virtual machine gave them the opportunity to acquire a general conceptual sketch, which is useful to understand and to organise information subsequently given by hypermedia. If notions are provided without such a preliminary mental framework, it is difficult to make sense of them. In the second case learners already had a model of the lathe: they did not need to acquire preliminary reference points; for these students learning requires linking abstract notions to real elements. For this reason they perform better when the interaction with the virtual lathe follows the hypermedia exposure: in this way, in fact, they can find the parts mentioned in the text in the 3D-simulation of the machine and they can see how the operations described verbally can actually be applied.

According to the theoretical framework adopted, it has been argued that the construction of a mental model requires that some separate elements are integrated into a whole structure (Gentner & Stevens, 1983; Johnson-Laird, 1983). Applying this perspective to the case of learning what a lathe is and what is it for, it can assumed that understanding requires students to be able to represent its parts correctly assembled and to identify their functional roles. In fact, learners must know not only how the lathe is arranged (the kind of knowledge involving physical and spatial relations) but also how it works (and this involves temporal, cinematic, dynamic and causal relations). Thus, since this type of understanding includes procedural aspects, relevant sources of information are not only notions and concepts acquired through reading text and viewing pictures, but also trials and feedback experienced through action. In the prototypal system considered here both kinds of sources were available because hypermedia provided concepts and VR gave the opportunity for a motor-perceptual way of learning.

VR-Hypermedia produced the best results for novice students whereas Hypermedia-VR produced the best results for expert students. In the construction of a mental model some elements play the role of pivot-cues or of 'pegs' to which the other elements can be linked. Presumably, different levels of familiarity with the contents to be learned induce people to prefer a particular kind of such 'pegs'. Novice students prefer to begin by fixing some concrete 'pegs' derived by motor-perceptual experience; expert students prefer to improve their preliminary knowledge first by activating conceptual 'pegs' and then by relating to these elements the new elements they discover by direct experience through action.

It must not be overlooked that these studies have some limitations. The VR and hypermedia system described was devised to be used in instructional environments in addition to other devices and procedures. It was not meant to replace teachers, lectures, exercises, lessons, and so on. However, these studies, lacking a control condition consisting of students who did not use the virtual machine, could not show if and what the prototypical lathe adds to traditional instruction. Further, in order to assess the benefits produced by the virtual lathe in machining learning, transfer from (declarative and procedural) knowledge representation to actual skills should be tested. This might be the goal of further research which should study the efficacy of the prototype in a real school setting.

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