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► **To cite this version:**

Alexandre Francis, Marc Couture. Credibility of a simulation-based virtual laboratory: An exploratory study of learner judgments of verisimilitude. *Journal of Interactive Learning Research*, 2002, 14 (4), pp.439-464. hal-00190653

HAL Id: hal-00190653

<https://telearn.hal.science/hal-00190653>

Submitted on 23 Nov 2007

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**CREDIBILITY OF A SIMULATION-BASED VIRTUAL LABORATORY:
AN EXPLORATORY STUDY
OF LEARNER JUDGMENTS OF VERISIMILITUDE**

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August 2002

This manuscript was submitted as is (except for formatting) in August 2002 to *Journal of Interactive Learning Research*, and later published in this journal (vol. 14, no 4, 2003, p. 439-464) with the [following modifications](#) (consisting of an updating of references and minor style corrections).

The official published version is available online: <http://dl.aace.org/14217>

ABSTRACT

Several studies have examined realism and instructional effectiveness of physical simulations. However, very few have touched on the question of their credibility or verisimilitude, from the user's point of view. This article presents an empirical exploratory study which investigated the perceptions of potential users of a simulation-based virtual physics laboratory (the VPLab). In the VPLab, students conduct virtual physics experiments designed to promote both acquisition of general experimental skills and conceptual learning. The objectives of the study were to uncover (1) users' preoccupations and representations related to the VPLab's verisimilitude, (2) the cues enabling users to make judgments of verisimilitude about the VPLab, and (3) the roles played by these cues in the expression of user judgments. Following a qualitative and descriptive approach, the study included in-depth interviews with thirteen first-year university science students. As part of the results, the complex and idiosyncratic nature of user verisimilitude judgments was highlighted. Furthermore, connections were established between these judgments and individual traits of users, such as prior use of certain computer applications. The influence of various aspects of the environment on its verisimilitude was also considered. These aspects included features expected to favor the VPLab's credibility, such as video sequences of actual experiments.

INTRODUCTION

It seems extraordinary that while computer simulations are becoming increasingly prevalent, we know so little about users' perceptions, expectations and attitudes concerning their credibility. (Hennessy & O'Shea, 1993, p. 129)

This statement on the importance of simulation credibility seems to have been largely overlooked; as a result, knowledge about users' perceptions of credibility has made very limited progress since the appearance of Hennessy and O'Shea's paper. This is unfortunate considering that, as these authors point out, this issue has "significant implications for simulation designers who want their systems to be of educational value and their interfaces to be designed in a principled way." (p. 130) Indeed, simulation credibility has yet to be addressed systematically, as few researchers – other than those who have studied *presence* (Lombard & Ditton, 1997) in simulation-based environments – have investigated some form of credibility or perceived realism.

For the most part, the following questions have not been given due consideration. How do users perceive computer simulations of physical systems? How do they perceive metaphors and interfaces that allow interaction with these simulations? To what extent are simulation-based environments real seeming to users? How does credibility affect use and effectiveness of such environments? In which way, if any, does credibility affect the motivation of users?

Our own interest in simulation credibility grew out of the process of designing and usability testing a simulation-based learning environment, Télé-université's Virtual Physics Lab (VPLab). Our main goal was to create an engaging and effective environment allowing college or university students to acquire not only basic experimental skills, but also a better understanding of physics concepts and laws related to specific experiments. We were convinced that, in order to reach this goal, the design of the environment should ensure that performing virtual experiments would be seen by students as relevant, useful and enjoyable.

While previously conducting usability tests of the VPLab, we had found that participants spontaneously brought forward elements of discussion relating to credibility. As for reasons why this would happen, perhaps the very fact that the VPLab was designed with concerns of credibility in mind can at least partially explain why these participants considered credibility (and *verisimilitude*, often referred to as *realism*) to be an issue. On the other hand, it seems only natural that some participants, when faced with a simulation-based laboratory, compare the learning experience afforded by this type of environment with that possible in laboratory settings. In any case, we observed that students themselves seemed to attribute some importance to how realistic and convincing they perceived this simulation-based environment to be. Hennessy and O'Shea (1993) expressed similar concerns, as they investigated elements of credibility in a simulation-based environment used by secondary-school pupils.

In this article, we briefly develop the concept of verisimilitude, which will be used to describe the credibility judgments of students more accurately. We then present an application of this concept to a detailed investigation of credibility judgments concerning a specific environment, namely a full-fledged, working prototype of the VPLab. Throughout

our analysis, we primarily discuss the characteristics of the environment that are more likely to be relevant for various types of virtual labs or learning environments.

To our knowledge, this study is the first to focus on the credibility of an environment designed for post-secondary students. What we propose here is to start mapping out this virtually uncharted field of user perceptions, through a relatively broad exploratory study using a qualitative and descriptive approach. As such, this investigation is also a means of surveying themes of research for future studies involving other simulation-based learning environments.

Before we get to the main part of this paper, let us first present some theoretical considerations about the closely related concepts of verisimilitude and credibility.

VERISIMILITUDE

We have chosen the term *verisimilitude* to designate the concept which we developed in order to study what users think about the VPLab. Verisimilitude literally means truth-likeness: the quality of appearing to be true or real (Barker, 1988, p. 43). In our approach, the concept of verisimilitude necessarily entails the notion of judgment.

Verisimilitude judgments are not the same as realism or fidelity judgments. Realism-fidelity assessments are expressed by domain experts (e.g., instructors, scientists) or by a community of such experts, using more or less well established criteria. Furthermore, we reserve the terms *realism* and *fidelity* to designate types of formal judgments made when comparing simulations to specific systems. Indeed, fidelity judgments (and even “psychological fidelity” judgments, cf. Hays, & Singer, 1989) are characterized by reference to very specific and agreed-upon objects, phenomena, or tasks (e.g., fidelity of a flight simulator when compared to a real DC-9 commercial jet).

In our view, the domain of verisimilitude encompasses more informal (and more partial) judgments expressed by media users like students or trainees, who tend to draw from resources that are more readily available to them. For instance, users may make verisimilitude judgments based on their own limited knowledge and experience of *whatever they think* is represented by a physics simulation, or even on the simulation’s very nature as a computer-generated construction designed by humans. For one thing, verisimilitude is a more appropriate concept, with respect to the real-world learning situations relevant to our study, because there are no a priori guarantees as to the exact referents that will in fact be involved in students’ assessments of simulation-based environments like the VPLab.

Epistemologically, verisimilitude judgments are also different from fidelity judgments, as the former actually constitute second-order judgments. To be known, user verisimilitude assessments need to be described by analysts such as the authors: to this end, an analyst must produce his own assessment of the user’s verisimilitude judgment. At a basic level, the analyst can create, be involved in, assess and relate the conditions under which a user’s verisimilitude judgment is formulated. Evidently, this is not necessarily the case for formal fidelity or realism judgments, which are considered first-order judgments since only one type of judge (the expert) need be a party to the expression of such judgments.

To describe verisimilitude more thoroughly, we mainly consider concepts developed in two distinct fields of research: (1) communication studies pertaining to perception of television content, and (2) human-computer interaction research directly concerned with credibility of diverse computer products.

Modality: at the center of verisimilitude judgments

In communication and media studies, several researchers have examined the perceived reality, or *modality* judgments, of television content (for instance, see Elliot, Rudd, & Good, 1983; Chandler, 1997). These researchers identified various criteria involved in viewer judgments regarding the reality (or the realism) of media content. These can easily be transposed to the context of simulation use – as examples, consider the following (fictive) judgments, concerning a VPLab instrument, associated to four modality criteria:

- the criterion of *possibility* (e.g., “This instrument is impossible to construct in reality”);
- the criterion of *plausibility* (e.g., “This instrument could be constructed but it’s highly improbable that you would find one in a lab”);
- the criterion of *actual existence* (e.g., “This instrument could be made but I would say that nothing like this actually exists in reality”);
- the criterion of *constructedness* (e.g., “This is just a virtual instrument and not a real one – it’s pre-programmed”). This criterion is defined by reference to a mediated phenomenon’s very nature as a construction or virtual entity.

The above criteria have allowed us to refine our basic definition of verisimilitude – the quality of appearing to be true or real – by identifying the types of judgment considered relevant; one should note, however, that systematic classification of user judgments according to such criteria is beyond the scope of this exploratory study. In addition, we are very interested in other judgments which seem to lie somewhat outside the domain of modality proper. User assessments of the pedagogical value of activities performed within the VPLab are equally pertinent to our research, provided that these assessments are made with at least some reference to real-world laboratory activities. This notion is analogous to *perceived utility*, identified by Potter (1988) as a component of the perceived reality of television.

Trust-Credibility and Verisimilitude

Verisimilitude can be linked to the concept of *trust* as developed in Human Computer Interaction studies, the second field of research from which we draw. In a review essay of computer credibility, Tseng and Fogg (1999a, p. 81) warn that the word *trust* bears at least two different meanings in HCI literature. According to the first meaning, which is not relevant to verisimilitude, *trust* indicates:

. . . a positive belief about the perceived reliability of, dependability of, and confidence in a person, object, or process. For example, users may have trust in a computer system designed to keep financial transactions secure. We suggest that one way to interpret trust [in this sense] in HCI literature is to mentally replace it with the word *dependability*.

The second use of the word *trust* refers to credibility (as in “trust the information” or “believe the output”); this latter meaning is relevant to verisimilitude. Tseng and Fogg suggest various terms which can be used to assess trust or credibility of computer products. These include: *believable, truthful, unbiased, reputable, well-intentioned*. Elsewhere, the authors also discuss the potential importance of credibility for simulation:

Credibility is important when computers run simulations, such as those involving aircraft navigation, chemical processes. . . . In all cases, simulations are based on rules provided by humans – rules that may be flawed or biased. Even if the bias is unintentional, when users perceive the computer simulation lacks veridicality, or authenticity, the computer application loses credibility. (Tseng & Fogg, 1999b, p. 41)

According to these authors, then, there exists a direct connection between “perceived lack of veridicality” (or, in our terms, lack of verisimilitude) and lack of credibility. We share this point of view, and for the purposes of the present paper, we shall treat verisimilitude as a dimension of credibility (and a most important one, at that). Although the scope of credibility might be broader than that of verisimilitude, one may at least assume that these two areas share much common ground.

The bases of verisimilitude judgments

We have just discussed the relevant dimensions of verisimilitude judgments. We shall now examine elements which can serve as possible bases for such assessments. To characterize the bases of verisimilitude and credibility judgments, we draw again from computer credibility research. Tseng and Fogg (1999a, 1999b) have outlined four different types of credibility: *presumed* credibility (based on users’ assumptions or pre-conceived ideas), *reputed* credibility (based on what is reported by third parties), *surface* credibility (based on simple inspection of a computer product), and *experienced* credibility (based on first-hand experience of a product). Logically, both experienced and surface credibility judgments can at least partially be based upon what we call product-specific *cues*. These can include: perceived limitations of, or opportunities afforded by, the computer product; distinct aspects, qualities, or physical features of the computer product, as perceived by the user; etc.

In our exploratory study, we mainly investigate presumed credibility – related, in this case, to the ontological status of computer simulations – and experienced credibility, which we must point out is based on a relatively short duration of interaction with the VPLab. In our opinion, it is very difficult or even impossible, in reality, to definitively isolate these two types of credibility from each other. An important postulate of ours is that assumptions, pre-conceived ideas, stereotypes, etc., may be at work in a user’s credibility judgments even when an outside observer (i.e., investigators such as us) has no ostensible evidence to this effect.

We have now defined the nature and scope of verisimilitude. With this concept as an overarching theme, the case study presented below explores various judgments expressed by potential users of the VPLab. The following research questions will guide our investigation:

- (1) What are the main preoccupations and representations that are significant to VPLab users in regards to verisimilitude?
- (2) What cues enable users to make judgments of credibility and verisimilitude pertaining to the VPLab and to its use?
- (3) What roles do these cues play in users' judgments?

METHOD

Description of the simulation environment used in the study

The Virtual Physics Laboratory (VPLab) is a simulation-based learning environment developed at Télé-université, a distance-education university. However, the VPLab's target users include on-campus learners as well as distance education students. For the latter, virtual labs will often be the sole or principal means by which they learn through experimentation. By contrast, in a school or campus-based context, virtual experiments are used mainly as a complement to regular laboratory work or as surrogates for specific experiments difficult to carry out in actual laboratory settings.

In the VPLab, students conduct virtual experiments (in mechanics) featuring many characteristics and constraints normally associated with actual experiments. These include uncertainty inherent to measuring apparatus, small random fluctuations of parameters, and limitations in the range or control the user is given over parameters and variables.

In fact, most components of the environment were designed following a strong *realism principle*, from which specific guidelines were derived. According to these guidelines, the simulated measuring apparatus, analysis tools, and experimental set-ups must look and function like their real life counterparts – or at least, as much as is allowed by cost and software limitations. Furthermore, the user must be provided with the same opportunities to act upon tools and objects than in actual labs. Departure from strict application of said principle was permitted at times, but only for ergonomic and efficiency-related purposes, and always after substantial – and sometimes heated – debate among the designers. Allowing for these considerations, the minimum requirement was that any feature or behavior, even if not encountered in actual set-ups, could still be considered feasible according to current scientific and technological knowledge.

This principle, which is further discussed elsewhere (Author, in preparation), distinguishes the VPLab from other simulation-based environments used in physics instruction. It is mainly justified by the dual purpose of the environment: the VPLab aims not only to provide insight into physical phenomena, like most science simulation software, but also (and even more importantly) to favor the development of skills related to laboratory work. Other simulation-based environments may allow higher degrees of control over simulated phenomena (compared to actual experiments) in order to create ideal or simplified experimental situations, often impossible to reproduce in real-life labs (e.g., no-gravity rooms, no-friction apparatus, user-defined numerical parameters with infinite precision). But this tends to widen the gap between the simulated and the actual setups, which is likely to restrain the range of experimental skills that can be acquired.

Once fully developed, the VPLab environment will include a dozen or so simulated experiments which, according to the above-mentioned realism principle, should be replicable in a real-world lab. For each experiment the environment offers five workspaces. The first two – called *Manipulation* and *Analysis* – present interactive simulations directly related to actual laboratory work. In these workspaces, users conduct virtual experiments much the same way they would in actual labs. They move objects directly by dragging and dropping them with the mouse cursor or, sometimes, by means of (simulated) motors driven by mouse clicks on a controller. They also use simulated apparatus and measuring devices which, with a few exceptions, offer no more features than their real-life counterparts.

In the present paper we will mainly be dealing with the Manipulation space (Fig. 1), wherein users interact with an accurately scaled – albeit videogame-like – depiction of an experimental setup. This image is surrounded by *floating tools* simulating devices that could be found in a school lab: a stopwatch, a calculator and, most important, a camcorder enabling the user to record events occurring in the simulation. These tools were also designed according to the realism principle, with occasional departures related to software or hardware limitations, to the 2-D nature of the environment, or to efficiency considerations.

At the bottom of the window, seemingly lying halfway between the simulated setup and the floating tools, one finds a control panel used to operate certain components of the setup.

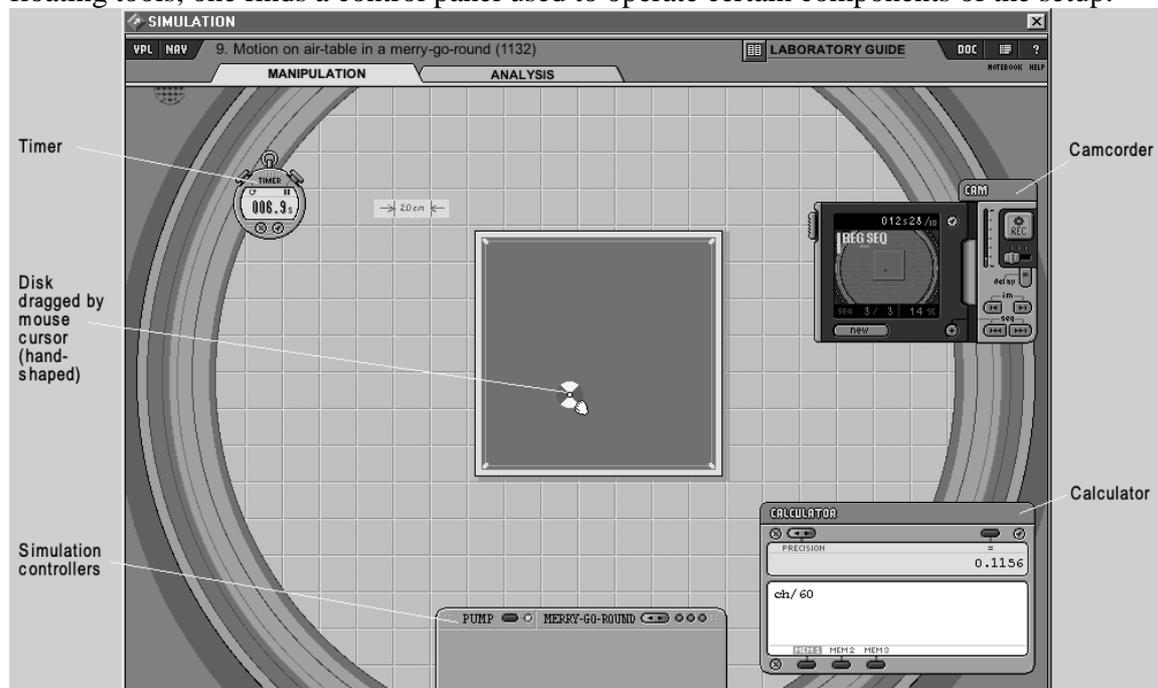


Figure 1. The Manipulation workspace of the VPLab, featuring a simulated setup (disk on an air-table in a merry-go-round), its remote controllers and the floating tools (calculator, camcorder, and stopwatch).

The Analysis space (not shown) features a different display of the same simulated set-up surrounded by various floating tools (Fig. 2), many of which are specific to the Analysis space. The difference here is that the apparatus can no longer be manipulated – instead the

simulation represents a monitor displaying a replay of events recorded with the camcorder in the Manipulation space.

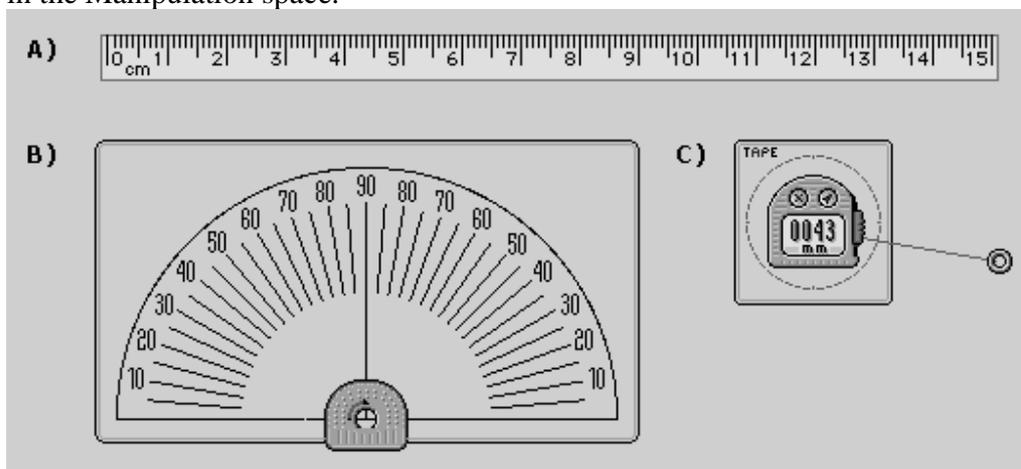


Figure 2. Measuring tools used in the VPLab's Analysis space: A) ruler; B) protractor; C) digital tape measure.

The other three spaces (named Presentation, Explanation, and Theory & Applications) consist of interactive multimedia documents. These offer animated comparisons between real and simulated set-ups (featuring video clips of real experiments), demonstrations of relevant physical situations, and mathematical and (or) physical explanations of the phenomena under study. In order to help bridge the gap between theory and laboratory work, all demonstrations and explanations closely match up against the simulated experimental set-up.

The simulated set-up used by students in this study was an air-table placed inside a merry-go-round (see Fig. 1). Within this simulation, users can grab the air-table and drag it anywhere on the floor of the merry-go-round by using a hand-shaped cursor controlled through the mouse. A disk can also be grabbed and launched on the air-table surface; the disk's thrust is controlled through cursor speed. A pump connected to the table may be activated to reduce most (but not all) of the friction between the disk and the table. The disk then glides almost freely across the table, and may repeatedly collide with the table's sides. Additionally, the merry-go-round (in which, as we recall, the air-table is placed) can be set to rotate at any of three predefined speeds. Accordingly, the disk motion will be influenced by non-inertial forces (centrifugal and Coriolis) in a manner similar to that of objects and passengers in a swerving vehicle.

User sample

Our sample consisted of thirteen undergraduate students from universities in Québec, Canada, majoring, or specializing, in chemistry (5 students), mechanical engineering (4 students), or physics (4 students). All but one participant (subject JW) were first-year students. All participants volunteered (and were remunerated) for participation in the study. Participants had had no prior contact with either the VPLab or Télé-université.

All participants had previously conducted physics experiments in school laboratories at university level, and had attended lab-based physics courses during the current or previous

term. Subject matter knowledge was not assessed through formal means, but some participants did exhibit more knowledge than others about the specific subject matter relevant to the experiment chosen for this study, i.e. forces in rotating frames of reference. Understandably, the physics students had taken more physics courses than the others. A number of participants had previously used real air-tables in an experimental context but some of those set-ups were significantly different from the air-table which served as referent for the VPLab's simulation.

All participants had much experience with computers and graphical user interfaces, but some were somewhat more confident about their computer abilities than others. There was also a broad spectrum of prior experience with simulation: for example, whereas one participant had tried out industrial flight simulators, another reported having no prior experience whatsoever with simulation. Notably, all engineering students had previously used high-precision Computer Assisted Design (CAD) packages to simulate components of mechanical systems.

Steps of the method

The method employed to collect data can be roughly separated into three steps. First, both written questionnaires and verbal interviews were used in order to detect elements that could influence verisimilitude, but which would do so, in large measure, regardless of the VPLab's specific features. We set out to identify preconceptions that seemed most likely to affect judgments concerning a broad class of simulation-based learning environments. Specifically, we tried to ascertain participants' expectations of what a lab course should involve as well as their preconceived ideas about simulation. Additionally, we gathered information related to participants' use of computers (prior experience with simulation, in particular) as well as information regarding general attitudes toward computers.

The second step consisted in allowing participants to interact with the VPLab through a series of activities representative of those that would actually be performed by novice users during an experiment. Many of the activities were exploration-based because of our assumption that novice users working from remote locations would probably use exploration as a preferred means of discovering the features of the environment. Also included were typical experimental tasks such as evaluation of uncertainty in measurements.

During the activities period, participants were encouraged to "think aloud" and discuss anything they perceived as either "strange" or "familiar". At this stage, this simple suggestion seemed the most appropriate way of having participants express judgments of verisimilitude. When participants mentioned an aspect related to credibility, we sometimes probed them on-the-spot (albeit shortly) in order to further understand their attitudes.

Before the activities, participants were told about the VPLab's general purpose, that is, "to teach experimental physics." However, the realism principle was never mentioned. We wanted to study the VPLab's verisimilitude on its own merits (i.e., its intrinsic capacity to appear to be real); it would therefore not have been appropriate to notify participants that the environment had been designed according to strong realism guidelines.

The third and last step consisted in debriefing participants in order to discuss any issues that could not be addressed while they were performing tasks. The first debriefing questions were quite general and open-ended. For instance, participants were asked how they felt about the VPLab in general, and what they thought of using the environment, in comparison to previous lab work. Participants then answered questions targeting specific dimensions of verisimilitude judgments (e.g., possibility and plausibility) applied to various aspects of their experience with the VPLab (e.g., actions they had performed or objects they had seen and used).

The total duration of sessions ranged from two to three hours.

RESULTS AND DISCUSSION

The following presentation and discussion of results is organized around important issues linked to various aspects of the VPLab. In keeping with the study's exploratory aim, we believe that the worth of our findings rests on the diversity of issues tackled and on a detailed exposition of differences among individual cases. Therefore, qualitative assessment of the relative importance of various issues for different individuals was a prevalent underlying process in our analysis. This was mostly accomplished by first considering each participant as an autonomous case and by looking for specific issues spontaneously evoked during the session, as well as elements mentioned when participants were asked general questions relating to overall credibility of the VPLab.

What we expose here is a general and contrasting view of verisimilitude judgments expressed by participants. We also try, whenever possible, to describe individual traits that seem to matter in accounts of specific verisimilitude judgments.

In the course of our investigation, we encountered user credibility concerns that had little or nothing to do with specific characteristics of the environment. One such matter dealt with the feeling of presence (or tangibility) in the simulated environment; because the general subject of presence in virtual environments has been studied to a fair extent in the past, we will not address this concern here. Another such issue was rather related to user judgments based on the VPLab's ontological status as a simulated environment – i.e., the environment's very nature. We discuss this topic first.

We then go on to examine a host of important issues concerned with verisimilitude judgments that involve specific cues which, though emerging from the VPLab environment itself, are relevant to a large class of simulation-based virtual labs. These issues relate to the viewing of video-clips of real experimental set-ups, to the behavior of the simulated apparatus and objects, to graphical attributes and visual presentation of the environment, to the type and precision of collected data, and to perceived freedom and control within the environment.

Note that we have chosen to conceal gender in our discussion, in order to inhibit unwarranted associations between certain attitudes and gender. Masculine pronouns and adjectives are thus used throughout for both male and female participants.

Ontological status of simulations

In this section, we describe observed expressions of lack of credibility more specifically related to the VPLab's ontological status as a simulated environment. These judgments involve the *constructedness* criterion of modality judgments (see Verisimilitude, above); they cannot be associated to any particular cue emerging from within the environment, but are instead inherently linked to the VPLab's nature itself.

We suggest that such lack of credibility can vary across a spectrum which ranges from the least radical to the most radical. One example of the least radical type was expressed by subject LY:

Of course, you tell yourself that [the teachers] are teaching a class so they won't hand you any old thing. Even so, they always tell you to act as if [what is being taught] isn't true until they prove it to you. . . . they say that you should always ask yourself questions concerning what the teacher is saying: maybe he's talking nonsense. . . .

You don't know [in the case of a simulation] if the programmer has taken the time to include everything – to really consider all the theoretical aspects and do the correct calculations – or if he just shoved the whole thing, and said: “Here, this is what it'll do.” [Maybe] a whole table has already been written up so that when such or such thing happens, [the disk] automatically goes the other way... Or, does it really work with a formula, with all values truly changing according to reality?

Through his comments here, subject LY addresses the issue of the underlying model's design, in relation to his own tendency to scrutinize what teachers expose in class. He asks a crucial question: If students should always start by being skeptical of what teachers expose, then why *should* they blindly trust instructional simulations at face value? In our opinion, this student is just manifesting a healthy skepticism towards simulation models. It seems to us that students, such as LY, who have computer science knowledge, might be inclined to display such attitudes.

Another case of the least radical types of judgment is exemplified by subject BO's attitude. This participant spoke of “the software taboo”: he believed that the most important obstacle to the success of the VPLab would be a lack of credibility that could occur if users felt that they were “just pawns in a game” and that everything within the VPLab had been pre-programmed to react in a determinate way when users followed a pre-determined path. However, this problem seemed to be successfully countered, in BO's case, by the presence of video clips “showing the experiment done with real objects” and by the possibility of free interaction with the simulated apparatus. As BO stated: “There is programming but it respects what happens in real life.”

At the other end of the spectrum, we find the most radical kind of judgment, like the one expressed by subject DQ which can be interpreted as a claim that there is an (undetermined) alteration caused by mediation of the experiment through the simulated environment:

DQ: . . . When you're on a computer, it's not real. I think that's the biggest difference between the two.

Interviewer: What would you think of a [virtual reality] lab where you could manipulate things using gloves? There would be objects... and there are gloves that give you tactile sensations. I was wondering if the problem [with the VPLab] was that you were working with a mouse and a keyboard or if it would be the same [problem] for you with a helmet and gloves?

DQ: It would be the same. It remains imaginary... well, imaginary, in a way of speaking. It's not imaginary but it's not real.

Another variety of radical-type judgment was expressed by JW. He brought up the question of simulation being vulnerable to tampering. There was also a link to the question of tangibility:

JW: . . . I think that there are some things which, even if you see them here [in the VPLab], you'll have the impression that they could be fully tampered with. For instance, when we watched the disk move in the video clip, you could see that it was real, but . . . it seems less real in the computer, when it's not a video clip. When you do it in a lab, you see it with your own eyes. Here [with the VPLab], you see it . . . but it's a machine that has done it all.

Interviewer: So it's the medium itself?

JW: Yes, it's the fact that I don't do things with my own hands – that I don't really look upon it.

Somewhere in the middle of the spectrum of ontologically-related judgments are attitudes like the ones displayed by ER, GT, IV, and KX. These participants exhibited *expectancy of ideal conditions* within the VPLab. For instance, subject ER expected that physical factors (a piece of pencil lead on the air-table, for example) which could cause experimental results to stray dramatically from theoretical predictions, would be absent from the VPLab's simulation:

. . . maybe such and such physical factor should be taken into account. I don't know... the window was open and a draft blew over my setup; but here [in the VPLab], you won't find that. . . . It's a computer, [so] everything goes well...

Videos showing real experiments

As expected, a number of participants (e.g., AN, BO, CP, FS, GT, IV) manifestly used the video clip (which they had previously viewed in the multimedia *Presentation* document) as a basis for judgments concerning simulated objects and events. In most cases, the video clip favored greater verisimilitude of the simulation or of the experimenter's role in the simulated environment. For instance, subject BO attributed great importance to viewing the video before he used the simulation:

Interviewer: So this [video clip] is important?

BO: Yes... You know, skeptical people will say: "Well this is all pre-arranged. It's software so it'll work just so – all I have to do is click and follow the path." With the video clip, they see that it's not just software – it's not just a simulation where you

click and it responds like so. [The video clip] shows you the experience done with real objects.

. . . That's why it's useful to see the video clip before. It provides an introduction so that someone who comes here [in the Manipulation workspace] and starts the merry-go-round will not be surprised at the disk's curved trajectory.

Interviewer: Because otherwise you would be surprised?

BO: Well novices would be surprised, not people who are used to it. . . .

Interviewer: Does the curved trajectory seem. . .

BO: No, it seems normal in comparison to the video clip that was shown earlier.

One should note that the simulation and the video clip offered the same, bird's eye view of the set-up. Comparison (albeit from memory) between the clip and the simulation was thus facilitated, a situation which probably favored verisimilitude further.

Participants appeared to use the video clip to judge different aspects of the environment: AN and IV referred to the video clip when considering their own roles in the experiment; BO used the clip to judge the experiment, as a whole, and also to assess the simulated disk's trajectory on the air-table; CP referred to the video clip to back up his claim that it was possible to find an actual merry-go-round in a lab; FS and GT referred to the video clip to assess the scale of the simulated objects.

Some participants (FS, GT, IV, HU) also referred to the video clip to assess the simulated disk's motion, but they often had to rely upon other cues, as certain behaviors were too briefly or not ostensibly displayed in the video sequence. In fact, a particular behavior not shown in the video clip seemed dubious to one of the participants (IV), who concluded by saying "But maybe it is normal," thus showing that he was not totally convinced either way.

From the preceding considerations, three important inferences can be drawn about the role of video clips. First, video clips depicting actual apparatus may enhance verisimilitude of simulations for certain individuals, in situations where the simulation and the video clip allow for close comparison. Secondly, different individuals may use the same video clip in different ways to judge various aspects of a simulation. Thirdly, for certain individuals, video may not be sufficient to secure credibility of all behaviors depicted by a simulation.

Finally, it should be pointed out that there are no direct indications that any of the physics students used the video clip as a basis for verisimilitude judgments. This may indicate that knowledge pertaining to the phenomena depicted by the simulation was an important factor influencing the use of video clips (or lack thereof) as a basis for verisimilitude judgments.

Behavior of simulated phenomena

Assessment of the simulated phenomenon, namely the disk's motion on the air-table, seems to have played an important role in regards to the VPLab's overall credibility. There were various types of bases for verisimilitude judgments concerning the simulation's behavior. As shown in the preceding section, the video clip was one such basis. Others included prior experience with similar phenomena in the real world (i.e., objects moving on air-tables),

and information drawn from explanations provided in the multimedia *Presentation* document.

In judgments concerning the simulation's behavior, different cues were important to different participants and assessments of the simulation's verisimilitude may have diverged depending on what cues were perceived or taken into account by different individuals. Such divergence can be observed by comparing comments from subjects AN and LY. In AN's case, the primary cue for overall verisimilitude was the unpredictability of the disk's motion. AN had launched the disk in such a way that its motion, initially back-and-forth, became irregular after a short while. Conversely, subject LY observed the disk repeatedly travel back and forth across the table, never deviating from a single straight path. This made LY claim that "the conditions were perfect" and that the disk would "totally react [according] to theory" (which is tantamount to attributing predictability to the disk's behavior, in opposition with AN's judgment). This comparison suggests that different observations of the very same simulation, corresponding to different sets of initial conditions, may lead to opposite conclusions as to its verisimilitude.

In another relevant matter, one of the cues used by a number of participants – namely, the disk's deceleration (caused by residual friction between the disk and the table, and by air friction) – deserves in-depth analysis for two reasons. Firstly, we wished to check the designers' assumption that this cue would lead to favorable judgments in terms of the VPLab's overall credibility. A second reason is that the investigation of perceptions regarding simulated friction could be insightful in studying how the simulation of a broad range of behaviors described by classical mechanics might be perceived by students, insofar as friction is an important phenomenon within this field.

At the outset, we had expected all participants to say that the mere presence of deceleration was an indication that the simulation took into account the friction working against the disk's motion. We were thus very surprised to observe that one subject (DQ) attributed the disk's deceleration to the merry-go-round's continuous rotation, while stating that the air cushion was not to blame because it was always stable (we are not too certain of what he meant). Another subject (GT) attributed the deceleration to a "loss of energy" for which he did not specify a cause, while making comments which would indicate that he was not aware of the existence of friction.

All other participants associated the disk's deceleration with non-zero friction, as we had expected. It has to be pointed out that the textual explanations in the multimedia *Presentation* document (consulted by most participants before they made their judgment regarding the deceleration) mentioned "a surface with very little friction," which indeed suggested the inclusion of friction in the simulation. However, one subject (KX) linked the deceleration to friction even before he viewed the *Presentation* document, while another (FS), after having consulted the document, still did not expect friction to be present. Hence, the textual explanations cannot be held completely responsible for the effectiveness of this cue, in all circumstances. Understanding of subject matter could well play an important role here, as enduring misconceptions about basic concepts such as force and acceleration have been observed among college or university-level students, even after thorough study of these concepts (see, for instance, Halloun & Hestenes, 1985).

Turning to another aspect of this issue, we observed that the apparent magnitude of the disk's deceleration was detrimental to verisimilitude for one participant (ER). Although ER did acknowledge the presence of friction, he felt that the disk was not slowing down fast enough. This led him to believe that air friction had been included in the simulation, but that residual friction with the table itself had not. Subject ER's prior experience of launching a metal disk on an air-table (as opposed to the much lighter plastic disk depicted in the video clip and simulation) must have been an important factor contributing to his judgment. On the other hand, another participant (CP), who had also had prior experience launching such a disk, did not find fault with the magnitude of the simulated disk's deceleration; contrary to the previous subject, he was very aware of the difference between the two set-ups, and suggested that it explained the difference in the disks' behaviors:

Interviewer: So it's normal to see this deceleration?

CP: Yes and it corroborates what would happen in a lab. But in a lab, you have steel disks so they slow down faster.

Overall, we can draw several conclusions from how participants judged the presence of the disk's deceleration and its rate. The first is that a realistic simulated behavior for which designers have high expectations in terms of contribution to verisimilitude may indeed be effective for several individuals. Others, however, might not react favorably. In these cases, real-world experience might help explain opposite reactions but it also may not constitute a sufficiently discriminating factor, as demonstrated by CP's judgment compared to ER's.

Another conclusion would be that even when an aspect of a simulation's behavior is considered to be "normal" or "realistic" by various users, different individuals might come up with different explanations for the same "normal" behavior. This is demonstrated by the surprising reactions of the two subjects (i.e., DQ and GT) who did not seem to associate the deceleration of the disk with the inclusion of friction in the simulation.

Yet another conclusion would be that some individuals may draw expected inferences between a given simulated behavior (the deceleration) and its intended cause (friction) without any prior explicit notice of the cause, as shown by the case of subject KX who linked the deceleration to friction even before he had read the *Presentation* document where friction was mentioned.

General visual presentation and graphical attributes

This section presents a number of issues related to the simulation's general visual presentation and graphical attributes. The first of these issues is closely related to the topic of the simulation's behavior, which was just discussed.

One of our findings in this area is that a number of participants (e.g., AN, ER, LY, MZ) could easily discern visual presentation of the disk's motion from its underlying model. One type of judgment expressed by two of these participants illustrates this capacity very well. It concerned the disk's motion, which was somewhat jerky at extremely low velocity, an effect related to the finite pixel dimension of the display. Observing this effect, both subjects AN and ER proposed that the software did not allow for smooth presentation of the motion and that the jerky movement was in fact representing low velocity. Subject AN

added that this was just a detail which did not bother him. We consider this account to be very significant, as it describes circumstances where visual fidelity (and, more importantly, *perceived* visual fidelity) is poor but where credibility is in fact preserved.

Another very important concern in this area is the question of whether a simulation's graphical attributes (or graphical complexity) create expectations as to its behavioral fidelity (or underlying model complexity). Once more, we found conflicting judgments expressed by different individuals.

Subject FS who, we recall, had thought that residual friction would not be included at all in the simulation, was led to this expectation by the Manipulation workspace's graphical attributes, which he considered "attractive" and "game-like". Here, his perception of the graphical attributes (as attractive) probably led him to imagine appropriate target users (beginners), and then to anticipate the simulation's level of complexity (simple).

Both subjects LY and BO showed an opposite attitude. LY thought that there "wasn't really a relation between content" and graphical quality. Later, he also said:

[The VPLab] is somewhat like SimCity [the video game] where everything is accounted for. These are software for which the graphical interface is not realistic – [but] you look at what happens [i.e., the content] and it's very realistic.

As for subject BO, though the simulation's graphics also reminded him of video games, he did not seem to think less of the VPLab – quite the contrary, in fact:

BO: The graphics aren't dull. Sometimes, because it's physics, [teachers] think that they have to make it boring. When you get textbooks and videos from the fifties in class, it's usually physics.

Interviewer: So does [the VPLab] look less serious to you?

BO: No. On the contrary, I think it opens some doors. It doesn't have to be ugly to be serious. It doesn't have to be boring for you to learn something.

Both the statements of LY and BO, as opposed to those of FS, seem to indicate that it is possible for individuals not to be overly influenced by a simulation's simpler visual presentation.

While subjects like BO and CP praised the VPLab's visual presentation, others displayed a more negative reaction (e.g., AN, ER, FS). Subject ER was the most displeased with the VPLab's visual presentation. Apparently it made the experience of witnessing the simulated disk's motion less convincing for him than seeing it in a real lab. He felt that the simulation's unusual colors (vivid hues of red, yellow, and orange were used in the Manipulation space) emphasized the fact that the images were actually drawings. To this, he added that the disk did not have the appearance of a real puck. Finally, he mentioned that seeing the apparatus (the air table) in a narrow space (see Fig. 1) was annoying and that it would be preferable to see the whole table in large. We conclude, from ER's reactions, that lower visual fidelity (through the cues described above) can be associated to lower verisimilitude.

For his part, subject AN believed that the VPLab's visual presentation could be improved if designers were aiming to impart a greater sensation of "palpability". Subject FS also

expressed a negative judgment concerning the VPLab's graphical attributes. During the debriefing interview, FS proposed that photo-realistic images – including elements such as “a nicer texture”, as well as instruments and colors that “look more real” – might help provide “a greater impression that [the environment] is real.” Note, however, that this student praised the VPLab for its “attractive” graphics – in comparison to non-commercial software – and said that these graphical attributes would help foster beginning experimenters' interest in working with the environment.

We believe that there are two types of attitudes at work here and that they are not mutually exclusive. It seems that some individuals (e.g., BO, CP, FS) find graphics like those of the VPLab attractive compared to the visual presentation of educational products (i.e., textbooks, software, etc.) which they encountered in science classes. However, some of these same individuals (e.g., FS), or others (e.g., AN, ER, JW), feel that those graphical attributes could or should still be improved in order to further promote presence or credibility.

Type of data, precision of measurements, uncertainty

Participants were invited to express judgments about the kind of data that could be collected within the VPLab and about the overall precision of measurements they could take. The latter was one of the areas where the realism principle had been of utmost importance in the design process: all simulated measuring tools (for examples, see Fig. 2) had been designed to circumvent the absolute, pixel based precision of the computer display, thus allowing for uncertainty assessment on all measurements.

A number of participants (e.g., CP, IV, KX) felt that the same kind of data could be collected within the VPLab as in a real lab. For instance, subject IV stated:

. . . all the elements are present to make it as if I was in a lab. All the instruments are provided so that I can obtain the same data as I would have wanted to obtain in a lab – that's what's important, I think.

Several participants (e.g., CP, GT, HU, IV, KX, MZ) used the precision of these data as an important criterion when making verisimilitude judgments regarding various elements of the VPLab. A priori, participants seemed to regard precision of manipulations and precision of tools as crucial elements of experimental work: during the preliminary interview, some participants (e.g., CP, DQ) said that they expected accuracy from their school's lab apparatus and that when it was lacking, this could become a source of frustration. Others (e.g., DQ, FS, GT) mentioned that they usually strove to achieve precise measurements.

When discussing this issue, participants sometimes referred to other computer software they had previously used (e.g., Computer Aided Design [CAD] packages, graphics creation software). One subject (GT) complained about the lack of precision associated with visual alignment of the VPLab's instruments onto graphical objects. He opposed this to using CAD-like functions which would have allowed him to fix tools very precisely onto objects being measured, or to otherwise obtain extremely precise measurements automatically:

. . . [in the VPLab] I have to rely on a screen with a zoom, with a [different] scale, and with pixels. It's really approximate, and I can't be sure that [the instruments] are aligned or... visually, it's hard to tell.

We believe that the *quest for precision*, as a value, is cultivated through lab work or any activity involving repeated use of precise instruments. Most participants were familiar with both lab work and use of precision tools. Among them, engineering students probably had had the most prior contact with high-precision instruments (GT, for instance, as a parts inspector in the field of aeronautics). It is entirely possible, however, that precision would be much less important, as a basis for verisimilitude judgments, to individuals not familiar with actual laboratory instruments and practices.

The issue of precision (or lack thereof) is directly linked to that of the assessment of uncertainty in measurements. Some participants, like subjects CP and ER, showed mixed reactions when asked whether it was surprising to be required to assess uncertainty of measurement while working with the VPLab. For CP, dissonance resulted from using "physics software" – the VPLab – which allowed for much less precision than what is available in most computer-assisted tasks. This student also felt he couldn't get as close to the measuring instrument (the ruler; see Fig. 2A) as he wished, because being too close to the screen was not optically comfortable. So, for both subject CP and subject GT, there was a negative aspect associated to the difficulty of aligning the tools on objects being measured, which is an important part of the uncertainty assessment process. CP did acknowledge, however, that uncertainty assessment was a normal part of physics experimentation.

Other participants (e.g., HU, IV, KX, LY) exhibited more approving reactions regarding uncertainty assessment. For instance LY, contrary to subject GT, commented favorably on the absence of a CAD-like *snap* function that would have allowed the user to fix the protractor (see Fig. 2B) very precisely on the vertices of the angle being measured. LY said that the absence of such a function allowed an uncertainty factor to subsist when making measurements. Later, when he was required to perform uncertainty assessment of measurements obtained with another tool – the tape measure (see Fig. 2C) – LY proceeded to do so with no hesitation. Afterwards, LY said that the method he had used to assess uncertainty was the same as the one he would have used in an actual lab. Apparently, it felt quite natural for LY to assess uncertainty of measurement within the VPLab.

We also have reason to believe that the act of requiring the user to perform uncertainty assessment was itself a positive verisimilitude cue, in some cases. For instance, subject AN said:

If you didn't ask me, I would surely say that [the data] is precise. But [uncertainty] is always there; they want to make reality more a part of it [the VPLab] . . . they want it to be closer to reality so they ask us to assess uncertainty so that we will really be working.

This issue does not actually involve a verisimilitude cue which is inherent to the VPLab environment itself, but instead one which is brought about by a potential task (uncertainty assessment) that a teacher might ask a student to perform. Of course, the very fact that uncertainty assessment is possible can also be taken as a cue favoring verisimilitude: it only

makes sense to require participants to assess uncertainty if the interface, and more specifically the measuring instruments, afford it.

As a matter of fact, at least two participants (HU, KX) spoke directly or indirectly of uncertainty even before they were required to assess it. Subject HU had this to say about the process of measuring distances within the VPLab: “. . . it’s really experimental in the sense that it is I [and not the computer] who measures the distance between dots. If ten people measured [a distance], there could be ten different results.”

The above discussion (and the beginning of the next section) shows that precision and uncertainty were important concerns relating to verisimilitude judgments of various aspects of the VPLab. This is interesting insofar as it suggests that some credibility concerns can be relatively common among members of the same population. Drawing another general conclusion, we may say that the credibility of limitations imposed by an interface (e.g., precision or lack thereof) can be assessed, as expected, in direct reference to real-world conditions (e.g., lab work), but it can also be assessed with reference to the capabilities of other computer applications (e.g., CAD packages).

Freedom and control within the simulated environment

In agreement with the realism principle, users could only launch the disk by dragging and releasing it with the hand-shaped cursor, in much the same way as in the real-world experiment. One subject (FS) did make comments indicating that this method allowed for sufficient precision in launching the disk, when compared to working with the real set-up; however, several others (e.g., BO, GT, HU, IV, KX, MZ) were dissatisfied with what they considered a lack of accuracy.

Precision notwithstanding, some of those same participants and others (e.g., BO, HU, FS) were satisfied with the general level of interaction provided through *direct manipulation* with the mouse and hand-shaped cursor (e.g., drag and drop of objects and apparatus components). For those students, *free interaction* with objects (i.e., almost as free as in an actual lab) and freedom to choose methods, coupled with direct manipulation, promoted overall credibility of the environment. For instance, free interaction was a most important verisimilitude cue in the case of subject BO who, as we recall, had expressed apprehension of being “just a pawn in a game” and a priori suspicions (apparently related to use of science tutorial software) that everything would be pre-programmed to react in a determinate way as one followed a pre-determined path. Interacting freely with the simulated apparatus alleviated these concerns:

[If] you do not have control over anything, then you might say: “It’s programmed to do that.” Whereas if you have control – to be able to move and touch everything that you desire, to throw and have fun with the disk for 15 minutes – you see that it’s not really programmed... there is programming but it respects what happens in real life.

For subject HU, the most important element that contributed to the VPLab’s verisimilitude was probably the freedom to choose work methods. This is linked, in our opinion, to the degree of control that one has over actions. As HU said:

I do everything, basically. . . . For instance, I can take five different measurements, with a tolerance of 1 or 2 millimeters, and calculate their average to obtain a more precise distance: [the computer] does not do it for me. It is I who chooses the measurement methods and the calculating methods . . . I choose my own way of proceeding.

In light of the foregoing examples, it appears that perceived control over objects and perceived limitations in regards to interaction constitute significant issues with respect to verisimilitude.

CONCLUSION

In this work, we probed users' perceptions relative to the credibility of a simulation-based environment. The qualitative method used has proven quite successful, as it allowed for the gathering and in-depth analysis of a wide variety of judgments concerning these matters.

Overall, our results indicate that user verisimilitude judgments pertaining to simulation can be very complex and specific. In particular, we observed that given cues in the environment could play different, even contradictory, roles in the formation of these judgments. We also found that, in some instances, unfavorable assessments could be promoted by cues designers had hoped would instead favor verisimilitude. Furthermore, our descriptive approach allowed us to begin showing that individual traits can be very significant in the expression of particular judgments. Such traits include prior use of certain computer applications, knowledge or experience of specific apparatus and related subject matter, and knowledge or experience of lab work in general. Indeed, it is especially noteworthy that some verisimilitude judgments seem to be at least partially based on prior experience pertaining to the medium of simulation itself.

With regard to interactivity, we may conclude that an interface which allows direct manipulation of simulated objects, and freedom to choose work methods, will be favorable to verisimilitude for certain users. The credibility of limitations imposed by the interface (e.g., precision of measurements, or lack thereof) can be evaluated, as expected, with reference to real-world conditions, but can also be assessed with reference to the capabilities of other computer applications.

One of our most important findings relating specifically to virtual labs concerns the perception of the simulation's behavior. We have indications that cues which point to inclusion of real-world constraints (e.g., a moving object's deceleration signifying inclusion of friction) often lead to favorable credibility judgments.

In a related area, we found that video clips showing the actual phenomena replicated by simulations were valuable assets in terms of credibility. However, our findings indicate that designers cannot necessarily expect meaning and verisimilitude of simulations to be completely circumscribed just by providing users with video data as common reference. Nevertheless, we suggest that future studies should test whether an even tighter coupling of simulation with video data could further promote credibility. For instance, one could provide users with video footage of strange or potentially unexpected behavior in real phenomena, and then later show participants that such behavior can indeed be observed in

the simulation replicating these phenomena. Other discursive cues, namely textual or graphical presentations and theoretical explanations of the simulation, also seem to influence verisimilitude judgments.

As stated above, we observed that verisimilitude judgments can often be complex. As such, future studies should ideally involve both rich qualitative descriptions of individual verisimilitude judgments pertaining to specific elements of virtual environments, as well as reliable quantitative measurements of overall credibility. Studies with large representative samples of users, working with a variety of simulation-based environments, are required to confirm and go beyond the findings of the present exploratory study.

An additional issue – which was not discussed above for methodological reasons but is nonetheless important – would also warrant investigations involving large samples. It is the question of a priori attitudes, or preconceived ideas regarding simulation as an educational medium. Preliminary findings concerning such attitudes are reported elsewhere (The authors, 2002); in particular, possible links between these attitudes and presumed credibility have been considered.

Moreover, attitudes resulting from prolonged use of simulation-based environments should be given very special attention, in order to investigate the full realm of experienced credibility. For practitioners, it is crucial that the value of simulation as a credible medium be assessed not only by taking into account the initial reactions of users, but also by considering their attitudes when sufficient experience of use has been acquired. We also need to find out how perceptions of verisimilitude affect user motivation, performance, and achievement of goals (e.g., transfer of skills, instructional effectiveness).

Furthermore, we recall that our investigation was conducted in a research facility rather than in users' normal work-settings (i.e., in school or at home). The extent to which this influences credibility judgments is unknown. It would be useful if at least some future studies were to be conducted in more natural conditions. In so doing, it is likely that investigators will not just be assessing the verisimilitude of simulation software as such, but also the credibility of whole units (e.g., learning units, training units) which, in addition to the simulation-based environment, also include external elements involved in its use (e.g., prescribed tasks, support materials, etc.) It should be paramount to include context of simulation use into some types of credibility studies.

Simulation verisimilitude should often also be addressed as a social phenomenon, in accordance with certain findings in other credibility-related fields (cf. Tseng & Fogg, 1999a, 1999b; Potter, 1988). In reality, simulation users interact with others and are influenced by their peers (e.g., classmates, instructors) and by information from other sources (e.g., television, movies). Moreover, the credibility of a simulation might be affected to some extent by the credibility attributed to the product's designer, to an affiliated institution, or to a third party (an instructor, for example) who suggests or imposes the use of that simulation (cf. Tseng & Fogg, 1999a).

Investigators could also explore the consequences of disclosing information to users concerning the inner workings of simulation models. To this end, a longitudinal study could be conducted whereby virtual lab users would be called upon to perform several experiments: after each experiment, these participants would be made aware of simulation

modeling methods and informed of hidden similarities or differences between the simulation and the actual apparatus. The idea would be to verify whether credibility of a virtual lab can be progressively enhanced, from one simulated experiment to the next, by showing users how designers “have done their homework.”

At the same time, how we promote verisimilitude and credibility constitutes an important ethical issue, one that researchers should examine carefully (see The authors, 2002 for a brief discussion; see also Turkle, 1997 for related considerations). Such undertakings may involve influencing – and eventually perhaps, even profoundly altering – students’ beliefs about simulation and the complexity of various phenomena represented through this medium. Practitioners and researchers should therefore reflect upon the ethical correctness of the means whereby this may be accomplished, and the larger implications of doing so.

AUTHORS’ NOTES

¹The most recent version of the VPLab prototype, which is by and large similar to that used in this study, as well as a detailed description of the environment are available at <http://www.liceftelug.quebec.ca/gmec/vplab/lvp.htm>.

²Part of this research was funded by Canarie Inc., the Office of Learning Technologies (OLT), Télé-université’s *Fonds institutionnel de recherche* (FIR), and the TeleLearning Network of Centers of Excellence (TL/NCE). One of the authors (initials) wishes to thank Cogeco Inc. and the Faculté des Études Supérieures of Université de Montréal for additional support.

³The authors wish to express their sincere appreciation to Thierry Bardini for insightful comments on various drafts of this paper, and for continuously offering invaluable suggestions pertaining to conceptual, methodological and expositional aspects of this work. They also thank Stéphanie Barker for providing important references, as well as Francine D’Ortun, Ileana de la Teja, and Aude Dufresne for helpful discussions about these ideas. Finally, they wish to acknowledge the useful comments made by reviewers of a more substantial version of this paper, published as a LICEF Research Center Technical Report (The authors, 2002).

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