CENTRE DE RECHERCHE

L I C E F

Technical Report

CREDIBILITY OF A COMPUTER SIMULATION-BASED SCIENCE LABORATORY: AN EXPLORATORY STUDY OF LEARNERS' VERISIMILITUDE JUDGMENTS

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February 2002

LICEF02

Résumé

Le réalisme et l’efficacité pédagogique des simulations physiques ont fait l’objet de nombreuses études. Cependant, très peu d’entre elles abordaient la question de leur crédibilité ou de leur vraisemblance du point de vue des usagers. Nous présentons les résultats d’une étude empirique exploratoire des perceptions des usagers potentiels du Laboratoire virtuel de physique (LVP) de la Télé-université. À l’aide de cet environnement d'apprentissage, fondé sur la simulation, les étudiants effectuent des "expériences virtuelles", qui visent non seulement l’apprentissage de concepts et de lois physiques, mais aussi (et surtout) l’acquisition d’habiletés en matière d’expérimentation. Notre étude, utilisant une approche qualitative et descriptive, a été menée auprès de treize étudiants universitaires qui ont fait l’essai du LVP. Nous appuyant sur le concept de "vraisemblance", nous visions à mettre au jour (1) les préoccupations et représentations des usagers potentiels du LVP à l’égard de sa vraisemblance, (2) les repères, propres à l’environnement, sur lesquels ils s’appuient pour poser des jugements de vraisemblance et (3) les rôles que jouent ces repères dans leurs jugements. Nos résultats mettent en relief le caractère à la fois complexe et idiosyncrasique de ces jugements, tout en nous permettant d’établir des relations entre ceux-ci et des caractéristiques des usagers telles que leurs antécédents en matière d’usage d’applications informatiques, ou leurs attitudes a priori envers la simulation informatique en tant que médium éducatif. Nous démontrons également la pertinence et l’efficacité de l’inclusion, dans la simulation, de processus et d’objets avec lesquels les usagers sont familiers, ainsi que de séquences vidéo montrant les référents de la simulation.

Abstract

Several studies have examined realism and instructional effectiveness of physical simulations. However, very few studies have touched on the question of their credibility or verisimilitude, from the user’s point of view. This report presents an empirical exploratory study which investigates the perceptions of potential users of the Virtual Physics Laboratory (VPLab), an application developed at Télé-université. The VPLab is a simulation-based learning environment allowing students to conduct ‘virtual physics experiments’ in order to promote conceptual learning and (notably) the acquisition of general experimental skills. Our study, which is based on a qualitative and descriptive approach, was conducted with a sample of thirteen university students who tried out the VPLab. Relying on the concept of ‘verisimilitude’, our objectives were to uncover (1) potential users’ preoccupations and representations related to the VPLab’s verisimilitude, (2) the cues enabling users to make judgments of verisimilitude pertaining to the VPLab, and (3) the roles played by these cues in the expression of user judgments. Our observations highlight the complex and idiosyncratic nature of user verisimilitude judgments, allowing us, by the same token, to establish connections between these judgments and individual traits, such as prior use of certain computer applications and *a priori* attitudes toward simulation as an educational medium. In addition, we show the relevance of including representations of processes and objects that are familiar to users, and the value of providing video clips depicting the actual objects which have been simulated.

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1. 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)

Our knowledge about users' perceptions of credibility has progressed very slowly since Hennessy and O'Shea identified it as a "critical issue", despite other important developments in the related field of simulation fidelity. This is unfortunate when one considers that 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" (Hennessy & O'Shea, 1993). Indeed, simulation credibility has yet to be addressed systematically. In fact, it seems that few researchers (other than those who have studied '*Presence*' [1] 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? Are simulation-based environments 'real seeming' to users? How does credibility affect use and effectiveness of such environments? Does credibility affect the motivation of users?

Our own interest in credibility grew out of the process of designing and usability testing a simulation-based virtual physics laboratory– the VPLab. Our main objective was to create an engaging and effective environment that college or university students could use in order to learn physics concepts as well as important skills related to experimentation.

In distance education, virtual labs will often be the sole or principal means allowing students to learn through experimentation. In school and campus-based learning contexts, virtual experiments can be used to complement regular laboratory work, or they may serve as surrogates for specific experiments that are difficult to carry out in laboratory settings.

While previously conducting usability tests of the VPLab, we had found that subjects 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 partially explain that these subjects should consider credibility (and 'verisimilitude', often referred to as 'realism') to be an issue.

On the other hand, it seems only natural that some subjects, when faced with a simulation-based laboratory, compare the learning experience afforded by this type of environment, with the learning experience that is 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 the present work, we briefly develop the concept of 'verisimilitude' to help describe the credibility judgments of users more accurately. The major part of this paper then focuses on the application of this concept to a specific case: that is, interaction with a full-fledged, working prototype of the VPLab. Indeed, we used this prototype to conduct a detailed investigation of various aspects of credibility related to this type of environment. To our knowledge, this study is the

[1] For a review essay of 'Presence' , see Lombard and Ditton (1997).

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, with 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 environments.

Before we get to the main part of this report, let us first present an overview of the Virtual Physics Laboratory (VPLab), focusing on the characteristics and components of the environment most relevant to our study.

1.1. Télé-université's Virtual Physics Laboratory

The Virtual Physics Laboratory prototype is a simulation-based learning environment developed at Télé-université, a distance education institution. In this environment, students conduct 'virtual experiments' (in the domain of mechanics) featuring many characteristics and constraints normally associated with real experiments.[2] These include uncertainty inherent to measuring apparatus, small random fluctuations of parameters, and limitations in the range or control the experimenter has over parameters and variables.

In fact, most components of the environment have been designed following a strong realism principle, from which 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 with respect to current scientific and technological knowledge.

This principle, which is further discussed elsewhere (Couture, in preparation), distinguishes the VPLab from other simulation-based environments used in physics courses, and is mainly justified by the dual purpose of the environment: the VPLab aims not only to provide insight into physical phenomena, like most simulation software, but also (and even more importantly) to promote 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 seemingly infinite precision). In doing so, however, they tend to widen the gap between the simulated setups and the actual ones.

1.2. The VPLab's workspaces

For each experiment (which, according to our realism principle, should be replicable in a real-world lab) the VPLab environment offers five workspaces. [3] The first two – called Manipulation

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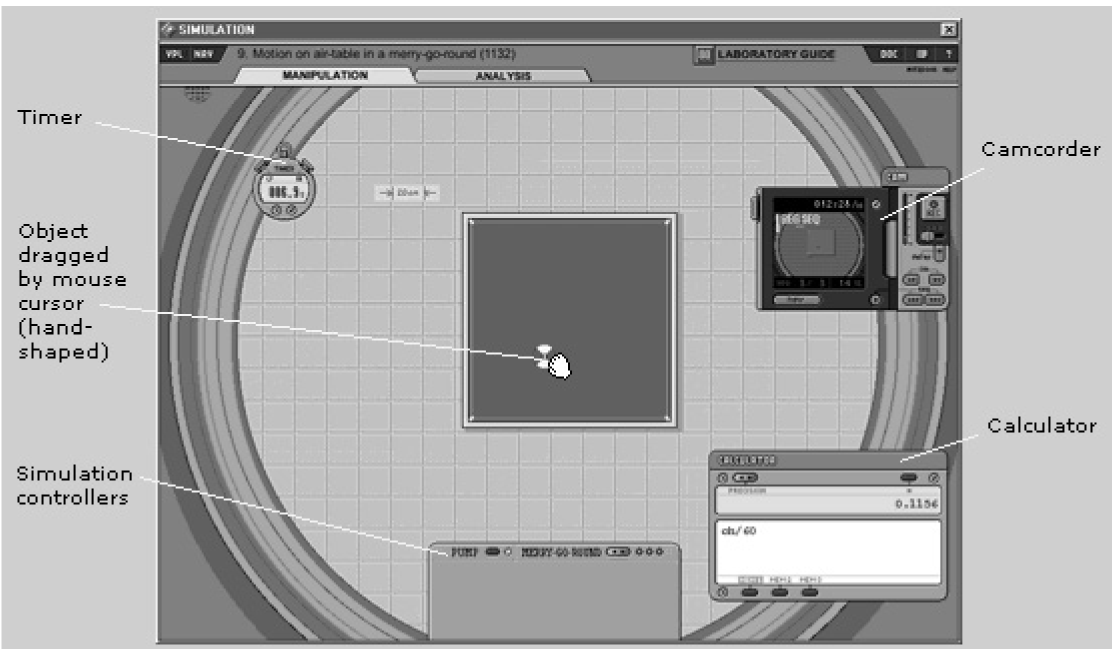
[2] Hereafter, we use the term 'experiment' alone when referring to the simulated experimentation activities to which students can participate when using the VPLab. In contrast, we use the expression 'actual experiment' to designate experiments performed with physical equipment, in school labs or similar settings.

[3] Note that all elements of the VPLab prototype used for this study were contained within Netscape Navigator™ windows (the Macromedia Shockwave™ plug-in was used to run the environment). Also note that a more recent version of the VPLab – which does *not* run within a browser – can now be downloaded by

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, with no additional control over the objects or apparatus provided. They may move objects directly by dragging and dropping them with the mouse cursor or, sometimes, by means of simulated motors controlled through mouse clicks on a control panel. To execute said experiments, learners use simulated apparatus and measuring devices which, with a few exceptions, offer no more features than their real-life counterparts.

In the Manipulation space (Fig. 1), users interact with an accurately scaled – albeit videogame-like – depiction of an experimental setup. This image is surrounded by a few ‘floating’ tools simulating those which could be provided in a school lab: a stopwatch, a calculator and, most important, a camcorder enabling the user to record the events occurring in the simulation. At the bottom of the window, 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 the simulated setup, its control panel and the floating tools (calculator, camcorder, stopwatch).



For most experiments, measurements and subsequent analyses are performed in a different workspace: the Analysis space (Fig. 2). The main component of this space is a special-purpose monitor (with zoom and multiple-image, or trace, capabilities) on which the sequences recorded in the Manipulation workspace can be reviewed using the camcorder controls. Various features of the monitor and several floating tools can be used to perform the required experimental measurements.

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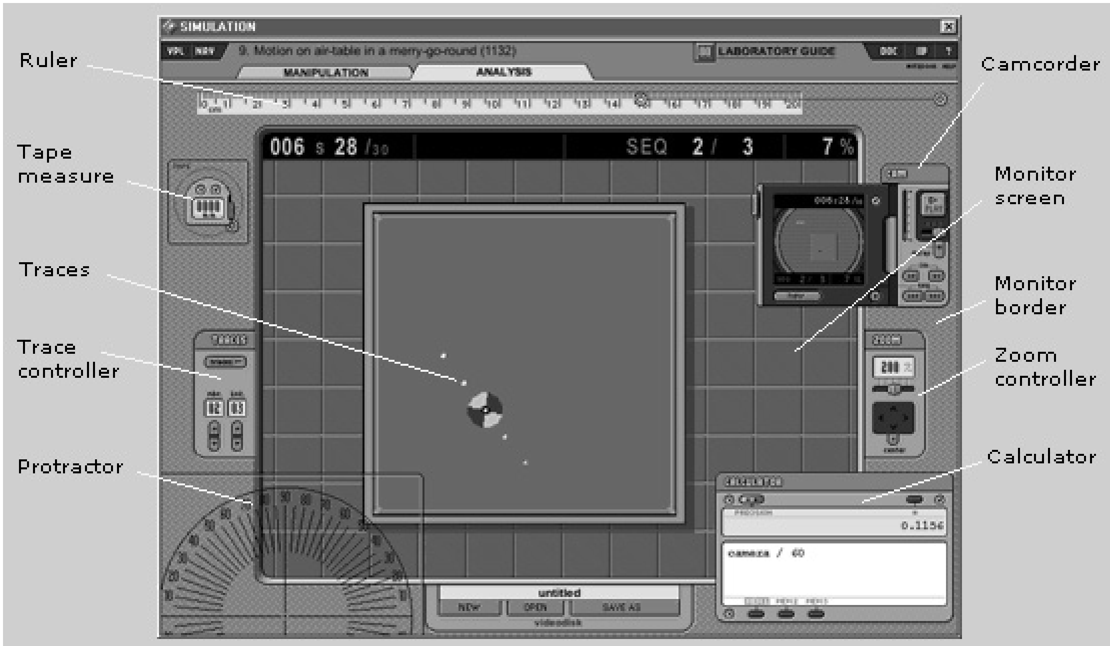
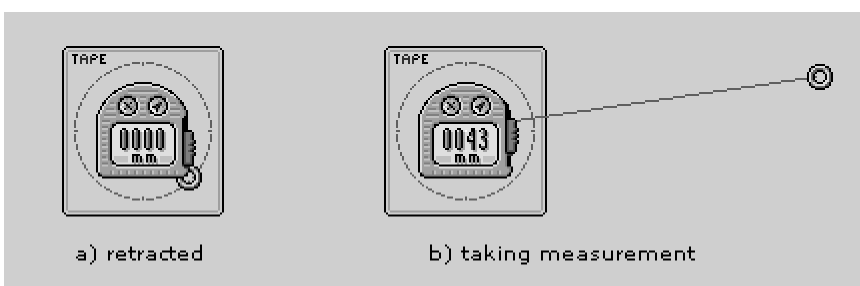
accessing the following web site: http://www.licef.teluq.uquebec.ca/gmec/vplab/lvp.htm. A more detailed description of the environment is also available on this site.

Figure 2. The Analysis workspace of the VPLab, featuring the replay monitor, its zoom and trace controllers, and the floating tools (calculator, camcorder, tape measure, ruler, protractor).



These tools have also been designed according to the above-mentioned realism principle, with occasional departures related to software or hardware limitations, to the 2-D nature of the environment, or to efficiency considerations. For instance, the digital tape measure (Fig. 3), though presenting many similarities with real tape measures, is not easily seen as having an exact real-life counterpart– in particular, one has to consider that real tape measures are usually manipulated with both hands. Other tools, like the ruler and the protractor, are much more similar to actual objects found in science classrooms.

Figure 3. Example of a measurement tool: the digital tape measure, shown with tape retracted (left) and extended for measurement (right).



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

The specific simulation used by subjects in this study was comprised of 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 the cursor speed. A pump connected to the table may be started to reduce most (but not all) of the friction between the disk and the table. The disk then moves 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. [4]

2. THEORETICAL CONSIDERATIONS

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). 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 in comparison to *specific systems*. Indeed, fidelity judgments (or even 'psychological fidelity' judgments, c.f. Hays, & Singer, 1987) 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 fabricated by humans. For one thing, verisimilitude is a more appropriate concept, with respect to the real-world learning situations relevant to our study, because we have 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 us: 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 expressed. Evidently, this is not necessarily the case for formal fidelity/realism judgments: we consider that these are 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,

[4] In our study, the disk motion was observed by most subjects both before and after the merry-go-round had been set to rotate. However, measurements were usually performed on the disk trajectory only with the merry-go-round at rest.

and (2) human-computer interaction research directly concerned with credibility of computing products.

2.1. 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).[5] Said researchers have identified various criteria involved in viewers' judgments of the reality (or the realism) of media content.[6] These can easily be transposed to our context– this is exemplified by the following (fictive) judgments, concerning a VPLab instrument, associated to four of these 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 type of judgment is defined by reference to a mediated phenomenon's *very nature* as a construction or virtual entity.

The above criteria allow 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 (note, however, that systematic classification of user judgments according to such criteria is beyond the scope of our exploratory study). In addition, we are also 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.

2.2. 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) 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' indicates 'credibility' (as in 'trust the information' or 'believe the output') and *is relevant* to verisimilitude. Tseng and Fogg propose various terms which can be used to assess trust/credibility of computer products. These include: 'believable', 'truthful', 'unbiased', 'reputable', 'well-intentioned'. Elsewhere, the authors also discuss the potential importance of credibility for simulation:

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[5] Also see Chandler (1997) for a review essay.

[6] Modality studies have involved television content of diverse 'genres' (e.g., cartoons, news, educational programs, dramas, sitcoms).

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 and Fogg, 1999b)

The last sentence of this quote bears closer inspection. According to the authors, "when users *perceive* that the computer simulation *lacks veridicality*, or authenticity [this phrase can often be replaced by 'when users perceive that simulated entities/events, or aspects of these, do not *exist*, or are not *plausible*, or are not *possible*'] the computer application loses credibility." This indicates a direct connection between "perceived lack of veridicality" (in our terms, lack of verisimilitude) and lack of 'credibility'. We adhere to 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.

2.3. Verisimilitude versus Presence

Turning our attention to a different concept, we must point out that verisimilitude can – and often should – be considered distinct from the recent, albeit well-known construct of 'presence', or 'tele-presence'. Initially, this concept was somewhat tautologically defined as "the sense of being in an environment" or "the experience of presence in an environment by means of a communications medium" (Steuer, 1992). It is related to the appraisal of efforts in enabling users to be "present" in a space other than that in which their body is located (for instance, in tele-manipulation, immersive Virtual Reality, immersive television, etc.)

Admittedly, this is an important issue, and one which has come up in the course of our study. Nonetheless, it is clearly not the main focus of our research. Although presence may somehow influence verisimilitude (or vice-versa), these two constructs are actually distinct, in our opinion. For one thing, we believe that it is possible for users to feel *present* in a simulated environment *and still* feel that it lacks verisimilitude if, for example, experienced events are not considered plausible or if the environment is not perceived as being internally consistent. Conversely, verisimilitude may not always lead to greater tele-presence: content conveyed through print media (e.g., a newspaper article) can be considered very plausible without providing much in the way of tele-presence.

Recently, an effort has been made to integrate verisimilitude-like constructs – called 'social realism', 'perceptual realism', and 'social reality' by some – into multidimensional 'presence' frameworks (see Lombard et al., 2000). 'Social realism', for instance, is assessed with the same kinds of criteria as perceived reality/modality (e.g., possibility of, plausibility of, existence of depicted events– although, 'social realism' criteria do not seem to include 'constructedness'). We argue that the use of such criteria within a presence framework raises major problems which further motivate us to distinguish 'presence' from 'verisimilitude'.

Interpreting and summarizing discussions that are relevant to the definition of presence (and which transpired on the Presence-l listserv, an electronic forum for announcements and academic discussion related to the concept of presence), Matthew Lombard states:

Social realism occurs ***when part or all of a person's perception fails to accurately acknowledge the role of technology that makes it appear*** *that s/he is in a physical location and environment in which the social characteristics correspond to those of the physical world […]* (Lombard, 2000 – our emphasis)

This definition of 'social realism' is in phase with Lombard's general definition of presence as "the perceptual illusion of non-mediation".[7] In our opinion, "failing to accurately acknowledge the role of technology" (i.e., illusion of non-mediation) should not be a *sine qua non* condition in the definition of verisimilitude judgments, or at least not for the sake of empirical investigation. In fact, when it comes time to *measure* user perceptions of social realism *as a dimension of presence*, these presence researchers do not always directly consider the condition of 'illusion of non-mediation' (perhaps because this condition *itself* may well be impossible to measure directly). Of course, potential connections between verisimilitude and 'transparency or invisibility' of the medium are worthy of study (including the extent to which a person may be aware of the role of technology in creating credible environments). Nevertheless, 'presence' should not be confused, *at the outset*, with the question of credibility, as such. We believe it entirely possible, in certain circumstances, for a simulated environment (or other mediated experiences) to be deemed credible by users, *without* the medium appearing to be 'invisible or transparent'.

2.4. 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 *basis* 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 distinguished by that which serves as their basis: *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 *a priori* attitudes toward computer simulation, as an educational medium – and *experienced* credibility (albeit based on a relatively short duration of interaction with the VPLab [8]). 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?

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[7] One way for this illusion to occur, say Lombard and Ditton (1997), is that "the medium can appear to be invisible or transparent and function as would a large open window, with the medium user and the medium content (objects and entities) sharing the same physical environment".

[8] It seems difficult to define the exact boundary separating *surface* credibility from *experienced* credibility. The individuals who participated to our study used the VPLab for a relatively short period (around two hours). Tseng and Fogg (1999b) propose that "*experienced credibility may be the most complex of the four types of computer credibility. Because it hinges on first-hand experience with the computer product, such credibility includes a chronological component that leads to a dynamic of computer credibility*." It can thus be said that we investigated the very first phase of the VPLab's 'dynamic of experienced credibility'.

(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?

3. METHOD

In our study, thirteen subjects each participated to one-on-one sessions during which they individually explored and used the VPLab. Participants were told about the VPLab's general purpose, that is, "to teach experimental physics". The environment's 'realism principle' was never mentioned however. We wanted to start by studying 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 subjects that the environment had been designed according to strong realism guidelines.

3.1. Steps of our method

Our method can be roughly separated into three steps. First, we used both written questionnaires and verbal interviews in an attempt to detect elements that may influence verisimilitude but which are, in large measure, independent of the VPLab's specific features. We set out to identify preconceptions that seemed most likely to affect judgments concerning this type of simulation-based learning environment. Specifically, we tried to ascertain subjects' 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 in our method consisted in allowing subjects to interact with the VPLab. They engaged in a series of activities similar to those that novice users would likely go through while performing an entire experimentation on the VPLab. 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 different features of the environment. We also included tasks that are typical of experimental work such as evaluation of uncertainty in measurements. [9]

During the activities period, subjects 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 subjects 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 attitude.

The third step in our method was to debrief participants in order to have them 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, we asked participants how they felt about the VPLab in general, and what they thought of using the environment, in comparison to previous lab work. Subjects then answered questions targeting specific dimensions of verisimilitude judgments (e.g.,

[9] It is true that the VPLab would normally be used in a somewhat more purposeful way and with resources like on-line help, a coherent and goal-driven pedagogical scenario (protocol), tutor assistance, peer collaboration, etc. None of these were available to participants because our interest was to identify verisimilitude cues that would emerge primarily from within the software environment itself and also because we did not have the resources needed to implement a method according to which subjects would conduct full-fledged lab experiments, analyze results and hand in lab reports.

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.

3.2. User sample

Overall description

As shown in table 1, our sample consisted of thirteen undergraduate students (recruited from universities in Québec, Canada) majoring, or specializing, in one of three science/engineering disciplines: chemistry (5 subjects), mechanical engineering (4 subjects), physics (4 subjects).

Table 1 Major of subjects

Discipline	Chemistry					Mechanical engineering				Physics			
Subjects	AN	BO	CP	DQ	ER	FS	GT	HU	IV	JW	KX	LY	MZ

All but one participant (subject JW) were first-year students. All subjects volunteered (and were remunerated) for participation in the study. Participants had had no prior contact with either the VPLab or Télé-université.

All subjects had previously conducted physics experiments in school laboratories at university level, and had attended lab-based physics courses during the current or previous term. Some subjects appeared to have more knowledge than others regarding the specific subject matter which applied to the experiment chosen for this study (i.e., rotating frames of reference), though note that subject matter knowledge was not assessed through formal means. Understandably, physics students had taken more physics courses than chemistry or engineering students. There was also a wide range of attitudes toward laboratory work. A number of subjects 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 a model for the VPLab's simulation.

All subjects had much experience with computers and graphical user interfaces, but some were somewhat more confident about their computer abilities than others. There was a broad spectrum of prior experience with simulation: for example, whereas one subject 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.

Description of *a priori* attitudes toward simulation as an educational medium

Because we felt that users' preconceived ideas concerning simulation could have major effects on their credibility judgments, we set out to investigate these beliefs. To this end, we developed a novel method with which we evaluated subjects' *a priori* attitudes toward simulation (as an educational medium), and more specifically the degree to which these attitudes were either *favorable* or *unfavorable*.

This procedure involved a questionnaire (filled out by participants before they explored the VPLab) containing descriptions of different pedagogical situations, each accompanied by 5-point scale items. Through these questions, participants were first asked to express confidence levels toward *simulation* in these situations, and then shortly thereafter, they were asked to express confidence levels toward *other alternative educational media* (video clips and training equipment) in those *exact same situations*. We made comparisons between pairs of near-identical questions involving simulation on the one hand, and the alternative medium on the other hand.

Tables **2** and **3** present classifications of the subjects according to the results of the process we have just described. This information allows us to evaluate how credible simulation was to participants, as an educational medium, even before they inspected the VPLab.

Note that it is more prudent to consider tables 2 and 3 separately because these classifications are based upon two sets of indicators involving distinct 'baselines– subjects' attitudes toward *video clips* were used for the first set, and their attitudes toward *fairly rudimentary training equipment* were used for the second. We strove to establish baselines appropriate for each type of pedagogical situation presented in the questionnaire (convincing students during a lecture, and training operators for various tasks). The two categorizations are wholly meaningful in their own right, insofar as the specific baselines are deemed adequate for each type of situation.

Table 2 thus presents a classification of the participants according to their *a priori* attitudes toward simulation **in comparison to *video*, when used to illustrate physics concepts**. This classification was derived from subjects' answers to questions involving situations where a teacher would try to convince skeptical students of the validity of a counterintuitive physics concept during a lecture.

Table 2: *A priori* attitudes toward simulation (in comparison to video) when used to convince skeptical students of counterintuitive concepts

***A priori* attitude toward simulation**		
Unfavorable	**Neutral**	**Favorable**
DQ, ER, FS, GT, HU, IV, KX, MZ	AN, BO, JW	CP, LY

Table 3 presents a classification of the participants according to their *a priori* attitudes toward simulation **in comparison to use of training equipment** (i.e., real equipment though simpler than that needed for the actual task), **for skill training**. This classification was derived from subjects' answers to questions involving the expression of confidence in operators training for various tasks.

Table 3: *A priori* attitudes toward simulation (in comparison to real, albeit simple equipment) when used for training

***A priori* attitude toward simulation**		
Unfavorable	**Neutral**	**Favorable**
DQ, HU	AN, GT, JW, MZ	BO, CP, ER, FS, IV, KX, LY

Again, to use this information appropriately, one must take into account that the two types of attitudes were evaluated with reference to different baselines. In light of this fact, if one wishes to consider both types of attitudes, interesting cases can be specified as follows:

– subjects *unfavorable* to simulation in *at least one* of the two cases (DQ, ER, FS, GT, HU, IV, KX, MZ).

– subjects *unfavorable* to simulation in *both* cases (DQ, HU)

– subjects *favorable* to simulation in *at least one* of the two cases (BO, CP, ER, FS, IV, KX)

– subjects *favorable* to simulation in *both* cases (CP, LY)

Evidently, it would be interesting to further investigate such attitudes with larger user samples. In regards to credibility, one could expect students to be generally unfavorable, a priori, to simulation as an educational medium. To our knowledge, no study has specifically examined this issue although, in a recent paper, Cartwright (1998) anecdotally reports: "*students knew that the data were computer-generated, and perhaps because of this, they always seemed to perceive such data as being less "real" than anything that came out of the back of a spectrometer.*"

Indeed, as is shown in the above tables, we did find students exhibiting such unfavorable *a priori* attitudes toward simulation (e.g., DQ and HU), but we also encountered favorable *a priori* attitudes (e.g., CP and LY)

4. RESULTS: CREDIBILITY JUDGMENTS AND VERISIMILITUDE CUES

We have organized the discussion of results around important issues linked to various aspects of the VPLab. In keeping with our 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. It therefore goes without saying that in-depth *qualitative* comparison between individual cases was the *motus operandi* for what follows. Qualitative assessment of the relative importance that different issues may have had for different subjects was a prevalent underlying process in our analysis of data relating to verisimilitude judgments and cues. 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 subjects were asked general questions relating to overall credibility of the VPLab.

The following exposition allows a general and contrasting view of verisimilitude judgments expressed by participants. Overall, we have found that verisimilitude judgments can be very complex. These judgments (and the cues involved) can vary considerably from one subject to the other. Concerns that seem very important for some subjects do not seem important at all for others. Even when subjects show the same concerns, it is not uncommon for their judgments to be contradictory or to involve important nuances relating to other particular concerns.

This idiosyncrasy has been observed several times and for a variety of issues. Individual traits of participants (e.g., interests; attitudes; aptitudes; experience with lab work, computers and simulation; knowledge of subject matter; etc.) appear to have been important factors influencing verisimilitude judgments. In what follows, we have tried, whenever possible, to describe individual traits that seem to matter in the accounts of specific verisimilitude judgments expressed by subjects. Among different types of individual traits, *a priori* attitudes toward simulation, prior experience of lab work, and prior use of certain computer applications figure prominently.

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. 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. As there have been several studies of *presence* in virtual environments, we will not be addressing this concern here. Instead, our first task will be to discuss the first topic which deals with ontologically-related judgments.

We will then go on to examine a host of important issues concerned with verisimilitude judgments that involve specific cues which emerged from the VPLab environment *itself*. These will include elements related to the VPLab's main metaphor, to the viewing of video-clips, to the behavior of the simulated apparatus, to graphical attributes and visual presentation of the environment, to the measuring instruments and their precision, to perceived freedom and control within the environment, to discursive cues, and to user anticipation of relevant pedagogical objectives.

4.1. The question of ontological status (and expectations of ideal experimental conditions)

In this section, we will describe observed expressions of *lack* of credibility more specifically related to the VPLab's ontological status as a simulated environment. These judgments fall under the *constructedness* category of modality judgments (see Theoretical Considerations); they can not be associated to any particular cue emerging from within the environment, but instead seem to be inherently linked to the VPLab's nature itself.

We believe 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:

> *[…] you'll always have limitations: is this really representative of the theoretical model ? What's behind this [simulation] to make [the disk] move like that ? Did [the programmer] take a formula and simplify it to allow for nice motion ? […] That's what bothers me: you have this software but you can have it do anything you want. […]*
>
> *Of course, you tell yourself that they 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 saying nonsense. With [the VPLab], you can't really question things because there's an [intrinsic] limit in using the program itself: if you start to question things at home like that, you lose the whole principle of using the software.*
>
> *You don't know 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 x 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 [10] comments here, subject LY addresses the issue of the underlying model's conception 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 subject 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. Since this problem seemed to be successfully countered, in BO's case, by the presence of video clips "showing the experiment done

[10] Masculine pronouns and adjectives are used throughout for both male and female subjects. As a precaution, we have chosen to conceal gender in order to inhibit unwarranted associations between certain attitudes and gender.

with real objects" and by the possibility of free interaction with the simulated apparatus, we believe that his ontologically-related judgment was of the least radical type. BO thus stated:

There is programming but it respects what happens in real life. [11]

At the other end of the spectrum is the most radical kind of judgment. One of these was expressed by subject DQ. We surmise that he exhibited a variety of judgment whereby one claims 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, 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.[12] These subjects exhibited *expectancy of ideal conditions* within the VPLab. For instance, subject ER *believed* that the air-table's sides (on which the disk had rebounded) were perfectly uniform and that it would be impossible to replicate them in an actual lab; subject GT was *convinced* that the pressure created by the air-table's pump was perfectly constant and that experimental results would be almost perfect compared to reality.[13] In a related matter, ER expected that physical factors (a gust of wind blowing on the disk, for example) which could cause experimental results to stray dramatically from theoretical predictions, would be absent from the VPLab's simulation: [14]

> *It's a computer, [so] everything goes well: there would be no physiological problems in the apparatus (e.g., a gust of wind blowing on the disk).*

---

[11] Notice that subject BO *fully acknowledges* the role of technology (programming), but *still* considers the environment as verisimilar. The existence of such judgments is the reason why Lombard's criterion of 'illusion of non-mediation', as included in his definition of *social realism* (Lombard, 2000), cannot be used in a valid operational definition of verisimilitude (see *Theoretical Considerations*).

[12] The cases of the subjects mentioned here are significant for this type of judgment because these participants did not also express more radical ontologically-related judgments.

[13] These types of judgments were expressed during debriefing periods, in the course of discussions which were instigated as a result of a hypothetical question that involved the VPLab.

[14] Rather than the term 'absent', ER used the word 'impossible'.

One may ask if there is a connection between unfavorable *a priori* attitudes toward simulation as an educational medium (see tables 2 and 3) and presence or radicalism of negative judgments based on a simulated environment's ontological status.

To examine this question, let us start by considering the aforementioned cases of subjects DQ and JW, both of whom expressed the *most* radical kinds of (negative) ontologically-related judgments. On the one hand, subject DQ was one of two subjects (HU is the other) who had exhibited unfavorable *a priori* attitudes toward simulation with respect to *both* of the situations presented in the preliminary questionnaire (convincing students in a classroom, and operator training). Hence, DQ's case supports the hypothesis of a connection between unfavorable *a priori* attitudes and negative ontologically-related judgments. On the other hand, subject JW's *a priori* attitudes toward simulation were *neutral* with respect to both of the questionnaire situations, so this case does not lend credence to said hypothesis (although its significance is somewhat mitigated since JW's *a priori* attitudes are neutral rather than favorable).

Next, let us discuss BO's and LY's statements classified as the *least* radical kind of ontologically-related judgment. Since these judgments were not radical at all, one would expect BO and LY to present *a priori* attitudes tending toward neutrality, if not approval, and indeed such is the case (see tables 2 and 3). LY even counts as one of two subjects (the other being CP) who exhibited *favorable* attitudes with respect to *both* of the situations presented in the preliminary questionnaire.

Finally, consider the statements of subjects ER, GT, IV and KX who expected *ideal* experimental conditions within the VPLab (recall that said statements were classified somewhere between the least radical type of ontologically-related judgments and the most radical type). Observe that all of these participants displayed unfavorable *a priori* attitudes toward simulation with respect to one of the situations presented in the preliminary questionnaire (convincing students in a classroom), but not the other (operator training). We see two valid, albeit opposite, ways to view these facts: either (a) these cases do not support the hypothesis of a connection between these types of judgments and *a priori* attitudes toward simulation, or (b) they do support said hypothesis and, if so, one must suppose that the unfavorable *a priori* attitudes toward simulation with respect to the first situation matter most in such instances. Proposition (b) becomes more plausible when the following additional case is considered: as we mentioned, subject CP displayed *favorable* attitudes toward simulation with respect to *both* of the situations presented in the preliminary questionnaire and, contrary to the subjects mentioned above (ER, GT, IV, KX), it so happens that he expected to encounter ***non***-ideal experimental conditions within the VPLab.

In view of the majority of the cases stated above, we believe that there may be a link between the expression of negative judgments based on a virtual environment's ontological status and the presence of unfavorable *a priori* attitudes toward simulation. An important and more general conclusion suggested by our data would be that preconceived ideas influence credibility judgments, and that this influence seems to be somewhat independent of concerns linked to *cues emerging from the simulated environment*. Related to this is the finding that students (e.g., subjects BO and LY) may make judgments of *constructedness* and still find a virtual environment credible.

We also wish to mention that some subjects (e.g., FS, JW) predicted that simulations like those of the VPLab would be more vulnerable to disbelief in situations where the simulated apparatus' behavior is strange or counter-intuitive. Let us, however, point to what we feel is a significant counter-example to this belief, through a specific account which concerns subject HU.

In the Analysis workspace, HU examined the disk's motion by measuring distances between successive positions in the disk's trajectory (which corresponded to successive time indexes).

During this exercise, a very interesting event occured: HU obtained a measurement which *ran counter to his expectations*. He then rationalized the existence of this seemingly *anomalous* result by saying that it was *normal to encounter it* since he was involved in "*practical work*".

Insofar as subject HU had exhibited unfavorable *a priori* attitudes toward simulation with respect to both of the situations presented in the preliminary questionnaire, it is fairly significant that he would *not* blame the VPLab's simulation for this seemingly anomalous result. What's more, during the debriefing interview, HU even went so far as to say that it was he, and not the simulation, who would be at fault if he were to obtain final experimental results which radically strayed from theoretical predictions (he also said that he was usually at fault when this happened in an actual lab). He claimed that he would *not* expect the computer to make mistakes.

Subject HU's statements may thus indicate that it is possible for students who have unfavorable preconceived ideas toward simulation, to be 'won over' by simulated environments that they eventually regard as credible.

4.2. The VPLab's main metaphor

(The virtual camcorder and the virtual monitor with its *Trace* and *Zoom* functions)

Below, we examine cues and issues that directly concern the VPLab's main metaphor, i.e. the virtual camcorder and the virtual monitor with its Trace and Zoom functions (see fig. 2). We use the term *metaphor* even if the VPLab's main representational device does not fit the canonical definition of a metaphor. From the designers' point of view, the VPLab employs direct mappings between *functionality* and *representation*, whereas metaphors usually "draw incomplete parallels between unlike things, emphasizing some qualities and suppressing others" and "*seed* the constructive process through which existing knowledge is transformed and applied to the novel situation" (Alty, Knott, Anderson, & Smyth, 2000). We shall see, however, that certain subjects perceived the VPLab as exhibiting some properties of metaphor-based systems.

As mentioned before, we observed that verisimilitude judgments could be very idiosyncratic. Some of this idiosyncrasy is vested in – and also seems to result from – the specific ways in which individuals interpreted the metaphor. In other words, subjects interpreted the main metaphor in their own way and this, in turn, seemed to affect verisimilitude judgments concerning the metaphor itself and related aspects of the environment.

Table 4 presents a sample of the different interpretations of the Analysis workspace's main display (virtual monitor) and virtual camcorder. These different interpretations are presented in order of degree of similarity to the meaning which the designers intended to convey. We have also enumerated cues quoted by subjects as contributing to these interpretations.[15]

Cues marked by an asterisk (*****) are cues that had not been included in an earlier version of the VPLab. When that early version had previously been tested with six other subjects, five of them had *not* understood that the Analysis workspace represented a display device and the remaining subject was not totally convinced that this was so.

[15] Other cues might have contributed to these individual interpretations without subjects being aware of their effect.

Table 4: Interpretations of the Analysis workspace's main display (virtual monitor) and virtual camcorder

Subject	Interpretation(s) of the Analysis workspace's main display (virtual monitor) and virtual camcorder.	Degree of similarity between the subject's interpretation and the meaning intended by designers	Cues that contributed to interpretation(s)
FS	The Analysis workspace's main display is a flat video screen which faces upwards. It is connected to the camcorder. Measurements are performed on the screen itself. Instruments can be set on the side of the screen. In the Manipulation workspace, there is uncertainty as to whether the camcorder is placed inside the merry-go-round or outside of it.	Extremely similar	-- The monitor's frame ***** -- The fact that instruments and panels outside the playback area (outside the virtual monitor's frame) remained in place and kept the same scale after zooming in and out (hence only the image inside the screen's frame varied in size) ***** -- Scale correspondence between Analysis workspace and Manipulation workspace
IV	The Analysis workspace's main display is like an oscilloscope: it is a very flat screen on which you can perform measurements directly.	Very similar	-- Monitor's time display (which was very similar to the virtual camcorder's time display) ***** -- The blue screen which preceded the first image of each 'filmed' sequence (this made IV realize that the camcorder's small monitor and the main monitor were both displaying the same images) ***** -- The colors (blues, violets and greens) used for the image displayed on the virtual monitor -- Grid-like pattern formed by the tiles on the virtual merry-go-round's floor (which, for IV, was indicative of a scale correspondence)
MZ	The Analysis workspace's main display is a television screen allowing measurement of the recorded video image.	Very Similar	-- Scale correspondence between Analysis workspace and Manipulation workspace
LY	The Analysis workspace's main display is a device (screen) which allows the viewing of a replay of things recorded.	Similar	-- The monitor's time display ***** -- The different color schemes used in the Manipulation and Analysis workspaces
BO	1- The Analysis workspace's main display is a *workbench* used to perform measurements. It's like recording an experiment	Similar	-- The blue screen which preceded the first image of each 'filmed' sequence (this made BO realize that the camcorder's small monitor and the

	with a camera and then watching the replay. Yet, writing on the display surface with a freehand-type function should be allowed. (2- BO also referred to a rapid photography rig with a phosphorescent marker to record successive positions and the use of an overhead projector for display purposes.)		main monitor were both displaying the same images) *****
HU	The Analysis workspace's main display is a camcorder (HU first expected that objects depicted on the main display should have the same scale as that of the measuring instruments).	Less similar	-- The monitor's time display ***** -- Scale correspondence between Analysis workspace and Manipulation workspace -- Performing a zoom-in -- Grid-like pattern formed by the tiles on the virtual merry-go-round's floor
KX	*At first*: The displayed image does not really seem like a recorded video sequence, as such. *When KX was asked specifically to interpret the metaphor*: The Analysis workspace's main display is a camera. *Later*: The Analysis workspace's main display is a board that presents results in an animated way.	Less similar	-- Scale correspondence between Analysis workspace and Manipulation workspace -- The different color schemes used in the Manipulation and Analysis workspaces -- The impossibility of manipulating the graphical objects which had previously been movable in the Manipulation workspace's simulation
ER	The Analysis workspace's main display is like nothing that really exists ; it's like a video game. (Difficulty in interpreting the metaphor.)	No similarity to intended meaning	(The control panels for the *Trace* and *Zoom* functions seemed to be cues for this interpretation.)
GT	Great difficulty in interpreting the metaphor in a functional way. The displayed image should behave like objects in a CAD package.	N/A	

If we compare these results with reactions to the earlier version of the VPLab, we see an indication that a more tangible representation of the metaphor (i.e., representing the monitor as a display area surrounded by solid, opaque borders containing a time display, and adding a smaller screen to the camcorder which bears striking similarities to the main monitor [see fig. 2]) helps users better understand the intended meaning of the VPLab's metaphor. Many subjects now equate the Analysis workspace's features with those of a display device, whereas none had done so when testing the previous version of the VPLab. In many cases, the exploration of the Analysis workspace and the performance of required tasks helped participants interpret the metaphor.

Concerning the camcorder's verisimilitude, many subjects judged that it was possible to use a camcorder in an actual student lab, but that it was not very probable due to considerations of cost. As far as the virtual monitor is concerned, it is interesting to observe that some cues which designers thought would contribute to verisimilitude, were actually conducive to unfavorable judgments for certain subjects. For example, CP and ER found bothersome the requirement of performing scale conversions (of measurements) and felt it did not correspond to anything that actually occurs in real labs. At the same time, it is true that other subjects [e.g., FS, IV, KX] were not bothered by this requirement– in fact, it might have actually helped them interpret the metaphor.

Another such example concerns the degraded graphical quality that results from zooming-in on the displayed image in the Analysis workspace. When certain participants (e.g., BO, LY, MZ) observed that the magnified super-imposed traces were not identical and that the overall definition of the image had degraded, they saw this as an unintentional computer artifact which they perceived as "artificial" or "reminding one that one was working on a computer".

The distortion that caused differences among traces was in fact intentionally included in the display by designers to simulate the limited resolution of existing camcorders and, at the same time, to promote uncertainty assessment. It is of great interest to note that such features included by designers, in part to allow students to gain knowledge of certain experimental procedures, may sometimes not yield greater verisimilitude and may even lead to lesser verisimilitude.

It must be said that the VPLab still incorporates some characteristics which makes it stray at least slightly from a perfectly *literal* interface (Smith, 1987), even by the designers' standards. For instance, the virtual instruments in the Manipulation workspace appear to float above the simulated scene (considering that the user, in this experiment, has a bird's eye view of the simulated apparatus) without them being tied to, or constrained by, anything. In a perfectly literal representation, however, the effects of gravity on the virtual stopwatch, the camcorder and the calculator should have been simulated in the Manipulation workspace and therefore these instruments should 'fall into' the simulated scene.

Additionally, users who recognize the main display in the Analysis workspace as a monitor or a television could suppose, contrary to what the designers wished to depict, that the screen's surface is perpendicular to the (virtual) ground – because monitors and televisions usually are in everyday life – and then infer that simulated gravity should take effect on the virtual instruments (because, as in the Manipulation space, these are placed on a 'layer above').

However, these gravity-related considerations did not appear to be issues in the verisimilitude judgments expressed by subjects. Either they did not analyze the metaphor in that detail or they took for granted that some things were different in a virtual environment and that these things did not matter.[16]

Nevertheless, some participants (e.g., FS, HU, MZ) did speak of another such issue, namely the view of the simulated scene afforded by the camcorder; for instance, they asked where the camcorder was located with respect to the merry-go-round. Perhaps these subjects raised issues of

[16] This would be consistent with the observations of Alty et al. (2000) who stated that human beings are very used to the metaphor concept and, as such, are not troubled by mismatches between metaphor and reality because they expect them.

this ilk because they sensed that the question of the observer's point of view was important when considering an experiment dealing with rotating frames of reference. On this topic, let us mention that a metaphor capable of presenting multiple points of view might have yielded greater verisimilitude. Not only would such a metaphor probably help improve visual perception of the simulated phenomenon[17], but it would also conform to an experimenter's capability of moving the camera around in an actual lab. Moreover, if users were allowed to inspect apparatus more closely (by changing their view-point) in order to detect potential anomalies, the practice of including anomalies or defects in experimental set-ups might seem less artificial or unfair. Indeed, some participants (e.g., CP, ER, MZ) claimed that inclusion of anomalies would be unfair to unwarned users, as such anomalies would be extremely difficult to detect– the fact that the user is confined to a very limited point of view was blamed among other factors.

Straying from familiar real-world experiences commonly shared by users

The metaphor's design aims to allow students to carry out operations analogous to those performed in actual labs. However, it can be inferred from our observations that most subjects were unfamiliar with at least some of the specific methods and technical processes which the designers sought to replicate through this metaphor– i.e., video analysis of recorded physical phenomena.[18]

Based on our observations, we believe that a virtual laboratory metaphor, like the VPLab's, which somewhat strays from representations shared by most potential users (in this case, university science students from Québec) favors diverging judgments within the user population. Note that, in our opinion, this divergence is much more likely to occur in situations where there exists little discourse (e.g., explanations) or social interaction to stabilize the meaning and verisimilitude of such a metaphor (i.e., when the user is 'left more to his own devices', as in our study).

This divergence may result of processes taking place, conceptually, on two separate levels. On a first level, initial *interpretation* of a metaphor may be more or less problematic, leading different individuals to ascribe various meanings, functions, uses and values to this metaphor. Differences in interpretation may arise, for example, as objects and events depicted through the metaphor are more or less familiar to users, in the relevant context (in our case, lab work).

We can appreciate, for instance, how different subject FS's interpretation is from ER's (see table 4). The interpretation made by FS is extremely close to the metaphor's intended meaning and involves association of the VPLab's devices with real 'advanced' analysis technologies, whereas ER's interpretation ("nothing that really exists" ; "like in a video game") lies at the opposite end of the interpretative spectrum. In contrast to ER's experience and attitude, subject FS's greater technological knowledge, enthusiasm for technology and use of video games might be factors which favored conformity of his interpretation of the metaphor to its intended meaning.[19]

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[17] In this regard, several subjects (e.g., subject HU) asked if they could be provided with another view of the apparatus, as they complained about troubles associating the effect of the merry-go-round's rotation to the disk's motion

[18] A possible exception to this was subject FS.

[19] However, other hypothetical differences between ER and FS might also explain the difference of interpretation. The critical difference between FS and ER might simply be that FS had a greater capacity to associate the VPLab's devices to objects and processes which would seem to be foreign (from a user's point of view) to the context of a physics experiment. Or, at a much more basic level, it might be that FS had a greater capacity or tendency to imagine possible three-dimensional referents (i.e., a real flat-screen facing upwards, around which there is a metal panel where instruments can be laid out) that could correspond to two-dimensional computer-generated depictions, presenting some ambiguity (one single 2-D depiction

In any case, taking into account the basic difference between interpretations made by these two subjects, we may go on to observe that FS's construal involving more 'advanced' analysis technologies probably had positive effects on verisimilitude judgments concerning *specific* elements of the metaphor: contrary to ER, subject FS felt that the Analysis workspace's digital *Trace* function [20] was somewhat plausible because he associated it to video devices that he had seen elsewhere (special effects used in hockey broadcasts). [21]

On a second level, differences in individual traits – including interests, attitudes, aptitudes, and familiarity [22] with recognized metaphor objects and events – and other factors may give rise to diverging judgments, even when different users have *similar* and acceptable understandings of what designers wish to represent through the metaphor.

Illustrating this divergence are the *differences* among verisimilitude judgments expressed by subjects MZ and LY who made *similar interpretations* of the metaphor. Near the end of the debriefing interview, subject LY was asked to estimate the probability of finding real-lab equivalents of the functions constituting the VPLab's main metaphor (recording an image sequence, viewing it, and using a trace function). LY answered that finding devices which replicated these functions in an actual lab was probable– that is, in a new school or a school which had kept up to date with recent technologies. Also, during the session, LY compared the *Trace* function to the carbon paper tracing system which he had used for an experiment conducted in college. LY appreciated the fact that the *Trace* function (like the carbon paper system) did *not instantaneously* provide needed information to the experimenter, but instead required him to do further work in order to obtain this information.

MZ's attitude stands in sharp contrast to LY's. During the session, MZ criticized the way that the metaphor structured tasks in the experiment. He felt it was strange that the experimenter had to make length measurements on "a television image" in the Analysis workspace instead of making them while handling the apparatus (in the Manipulation workspace). Also, even though he noted great similarities between the Analysis workspace's *Trace* function and a carbon paper tracing system he had previously used, he thought it peculiar that it was not left to the experimenter to decide if traces are to be drawn as the disk moves on the air-table. Considerations of pedagogical value, which seemed important to the previous subject, were manifest in MZ's judgment:

> *[…] even from a **pedagogical standpoint**, I think it's good that one should be required, while performing the experiment, to plan ahead and say:"I'm going to have to leave traces [of the trajectory] to be able to make measurements"*
>
> *Whereas here [i.e., with the VPLab], it's like we don't really care: we move the disk around, then we go to the Analysis [workspace] where we can do anything we want. For this aspect, maybe it's not very realistic.*

---

corresponding to a bird's eye view of the Analysis monitor with no additional views of this device's 'other sides').

[20] It is essential to point out that the choice of experiment (one with an air-table) has consequences for verisimilitude judgments of the metaphor, and especially for those judgments which concern the Analysis workspace's *Trace* function. In educational labs, air-tables are often used in conjunction with a tracing system that works by repeatedly sending electrical discharges on carbon paper. Students analyze the trajectories of objects thus recorded on the carbon paper as a series of dots. Had we chosen a different experiment for this study – one that was not traditionally linked to such a tracing system – verisimilitude judgments of the *Trace* function might have been very different (although not necessarily more negative). Note, however, that the experiment was not chosen with this in mind.

[21] This is also true of subject IV.

[22] The question of how to define familiarity with referents, in this context, on a continuum between simple awareness and prolonged hands-on experience is certainly not a trivial one.

During the debriefing interview, MZ further expressed negative judgments concerning the metaphor as a whole. He said that it felt artificial and that he could not imagine, as far as the specific air-table experiment was concerned, how replicating its functions in an actual lab could be advantageous. We believe that MZ's abilities and interests in experimental design were conducive to him expressing these types of judgments.

Leaving aside the question of divergence for now, one could say that verisimilitude judgments would probably tend to be more positive if individuals were faced with a metaphor based on more familiar devices or processes (in this instance, a system similar to the carbon-paper tracing system to which several subjects referred [23]).

Subject BO's case supports this hypothesis. This participant had had prior experience with the use of an actual air-table in an experimental context. The functionality of the rig he had then used to collect data, if more rudimentary, was in many ways analogous to the VPLab's functionality. It made use of rapid photography and a phosphorescent marker to record successive positions of the disk. Analysis was then performed by developing the film and projecting the pictures on a screen. It is true that BO found salient differences between this device and the VPLab's analysis system. Nevertheless, based on comments made by the subject, we surmised that these differences had a *negligible* negative impact on credibility because the *basic functions* provided by the VPLab's devices *were the same as the ones provided by the rig he had previously used*, so that the structure of the experimental methods were somewhat similar.

We believe that this question should be investigated further, as we suspect that a hypothesized counter-phenomenon (dubbed '*latency of favorable verisimilitude judgments*') could impede the expression of positive verisimilitude judgments in such a case. This hypothesis is examined below.

Latency of favorable verisimilitude judgments

We suggest that when a *high-fidelity* virtual environment is being used in *everyday life* (or in an ethnographical-like study which aims to observe use of virtual environments in *everyday conditions*), users' positive attitudes relative to verisimilitude tend to remain latent, as elements favorable to verisimilitude are taken for granted.[24]

That is: in everyday use, the more a virtual environment feels 'natural' to an individual (i.e., engrossing this individual, either by conforming to what he/she expects, or by seeming very similar to possible real-world environments, or else by being internally coherent and consistently stimulating perceptual mechanisms as accurately as real environments), the more the elements which contribute to this feeling of naturalness are taken for granted by that individual. Moreover, the remaining *perceived* differences between the virtual environment and the real world might 'stick out' and lead to the expression of negative verisimilitude judgments.[25] In other terms, for a user

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[23] Of course, there are practical issues that can hinder the implementation of such a metaphor, not the least of which is the issue of long-term usability (cf. Alty, Knott, Anderson, & Smyth, 2000) as well as the problem of designing an environment appropriate for many different types of experiments and not just those which would usually make use of a carbon paper tracing system.

[24] This could also be the case when some kind of metaphor is involved, say one that is based on very familiar objects, events and processes.

[25] Of course, if the user does not ***perceive*** any differences between the virtual environment and the real world, then he might well be lead to judge (perhaps even falsely) that the environment is extremely verisimilar, despite possible lack of fidelity.

habitually engaged in such a seemingly 'natural' virtual environment, it is 'business as usual' unless some feature promotes disengagement from the ongoing mediated experience.[26]

In the course of our study, we sometimes did get a sense that perceived deviations from reality (or rather, from the subjects' experience of reality) actually did 'stick out', but we cannot demonstrate this ostensibly with our data, since our method was not designed to do so. It is also our belief that certain 'positive' aspects of the VPLab's metaphor, by and large, were taken for granted or ignored.

One such aspect would be the 'first-person' perspective afforded by the interface. With the VPLab, the user's actions are not mediated by an on-screen anthropomorphic character that represents him as the experimenter (like in third-person video games). Instead, the user directly interacts with the instruments and apparatus via a cursor shaped like a hand and meant to represent the user's own hand. In this way, users may feel that they are 'personally' conducting experiments. This characteristic was hardly mentioned by subjects as contributing to verisimilitude.[27]

In our opinion, the importance of such an aspect would be more likely to emerge paradigmatically (cf. Barker, 1988) – in this instance, if users (either directly or mentally) compared various *potential* metaphors which could be alternatively implemented for the same virtual environment. This, however, was not part of our study's design.[28]

Notice that it would also be possible to test a similar assertion with other media. For example, one could observe if spectators exiting the viewing of films that are considered more or less 'realistic' by critics (i.e., movie experts), would naturally tend to discuss amongst themselves elements which give rise to greater verisimilitude or, on the contrary, elements unfavorable to verisimilitude. Our hypothesis is that the latter would tend to be true. In regards to virtual environments, let us also put forward that unfavorable *a priori* attitudes toward simulation (with respect to credibility) could exacerbate this hypothesized propensity for negative judgments to 'stick out'.

Regardless of the details, our first underlying premise is that – within given cultures, including ours – there is an asymmetry in verisimilitude judgments regarding certain mediated experiences (e.g., films, simulated environments). Our second premise is that this asymmetry favors the expression of *negative judgments* (this is not to say, however, that there will necessarily be more negative assessments than positive ones in a given context). If this can be somehow verified, it might be an important issue relating specifically to how verisimilitude judgments are investigated, but it might also be one which addresses the very nature of everyday verisimilitude judgments themselves. One could consider that said latency or asymmetry is itself part and parcel of the problem of designing credible virtual environments.

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[26] Bear in mind, though, that potential judgments based on its ontological status can always be expressed and are kept in check by the user's *willing suspension of disbelief* (Laurel, 1991; Goffman, 1974)

[27] Subject AN did mention that it was interesting to be "the master" of the situation and subject GT mentioned that the instruments were designed realistically, giving the impression that one could "handle them with one's own hands". Nevertheless, we do not believe that these comments reflect the specificity of 'first-person perspective', nor do they adequately convey its potential importance for verisimilitude.

[28] We believe that failure by our participants to specifically acknowledge the verisimilitude of the first-person perspective could eventually serve as first evidence of 'latency', that is, if another study using such a comparative method as described above, could demonstrate that this aspect can, in fact, favor verisimilitude. In a more descriptive/anthropological study, attitudes like subject BO's concerning the metaphor would rather tend to infirm this latency if they could be *spontaneously expressed during the use* of a virtual environment in a context as close to everyday use as possible.

4.3. Use of the video clip as a basis for verisimilitude judgments

As expected, a number of subjects (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 of 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.*

It is our belief that since the simulation offers the same point of view (bird's eye view) of the simulated apparatus as the one offered by the video clip, comparison (albeit from memory) between the clip and the simulation was probably facilitated– in our opinion, this must have favored verisimilitude further.

Subjects appeared to use the video clip to judge different aspects of the environment: AN referred to the video clip when considering his own role 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 disk's motion and the scale of the simulated objects ; IV used the video clip to evaluate his own role in the experiment and also to assess the disk's motion ; HU tried to use the video clip to assess the disk's motion but had a hard time doing so because the simulation did not offer a view of the air-table from outside the merry-go-round (as did the video clip, though very briefly).

Subjects who referred to the video clip to assess the simulated *disk's motion* focused on various aspects of this phenomenon: BO and FS considered the disk's behavior, in general ; GT focused on collisions between the disk and the table's sides (more specifically: the question of conservation of energy) ; IV was mainly concerned by the relation between the disk's trajectory and the merry-go-round's speed.

Despite the video clip's usefulness however, subjects often had to rely upon other cues in order to assess the disk's motion, as certain behaviors (e.g., the disk's slow deceleration after having been launched ; back and forth motion across the table on one straight path ; the disk getting stuck in a corner of the table, etc.) were not ostensibly displayed in the video sequence.

We can offer an example where behavior *not* depicted by the video clip seemed dubious to one of the participants. Subject IV felt it was strange, when the merry-go-round's speed was high, that the disk would sometimes become stuck in one corner of the air-table after having moved around a lot. “But maybe it is normal,” he added, showing that he was not totally convinced either way. In contrast though, another subject (FS) found this behavior quite normal, as he explained that it was the result of centrifugal force.

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 (as for subject IV), video may not be sufficient to secure credibility of all behaviors depicted by a simulation. Hence, although video is, in our opinion, a valuable asset in terms of credibility, we believe that designers cannot necessarily expect meaning and verisimilitude of simulations to be completely circumscribed just by providing common ‘referents’, in the form of video data, to all users.

Finally, we wish to point out that we have *no direct indications* that any of the physics subjects 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 use (or non-use) of video clips as a basis for verisimilitude judgments.

We also observed that only a subset (subjects FS, GT, IV) of those individuals who had displayed unfavorable *a priori* attitudes toward simulation *in comparison to video* tended to use the video clip as a basis for verisimilitude judgments concerning the disk’s motion. Other participants (DQ, HU, KX) who seemed to have exhibited strongly unfavorable *a priori* attitudes did not refer to the video clip in such judgments. These questions should be investigated further.

4.4. Behavior of the Manipulation workspace simulation
(The disk’s motion on the air-table, in the merry-go-round)

Assessment of the disk’s behavior on the air-table seems to have been relatively important in regards to overall credibility of the VPLab. It must be said that one of the session’s activities was specifically designed to expose subjects to the disk’s behavior and observe what judgments they would express. [29]

Nevertheless, by no means does this fully explain why there were so many important judgments relating to the simulation’s behavior: indeed, several subjects (e.g., BO, FS, HU, IV, KX) also expressed opinions concerning the simulation’s verisimilitude during the preliminary exploration-based tasks for which no specific goals had been set (except to explore, of course) and some of these judgments were unprompted. Yet, the significance of the simulation’s behavior with respect to overall credibility is not very perplexing to us because, as a surrogate for the real setup, it is the focus of attention in the experiment.

Many types of elements seem to have served as basis for verisimilitude judgments concerning the simulation’s behavior. As we have shown in the preceding section, the video clip is such an element. Others include previous real-world experience with objects moving on air-tables, as well as information drawn from explanations (pertaining to the simulation) provided in the multimedia *Presentation* document.

[29] After having explored the Manipulation workspace to their satisfaction, subjects were directed to turn on the pump, to launch the disk as fast as they could on the air table, and then to launch it again as slow as possible in order to observe its motion (the merry-go-round was not in rotation). While the disk decelerated, the interviewer asked subjects what they thought of the motion.

Again, in judgments concerning the simulation's behavior, different cues were important to different subjects 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 made by subjects AN and LY. In AN's case, the primary cue for overall verisimilitude was the *unpredictability* of the disk's motion. This was probably related to AN's observation of the disk's motion after he had launched it very precisely in one corner of the table: after going back and forth twice across the diagonal of the rectangular table, points of impact with the table's sides started to get away from the corners and collisions started to occur at different places on the sides of the table. Conversely, when subject LY launched the disk straight towards the table's side (at a 90 degree angle), he observed that it traveled back and forth on the table surface without deviating from a single straight path. This indicated to LY that he could launch the disk at a perfect 90 degree angle (to the table's side), and that the table's surface and sides "were perfect" ; the subject claimed 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). Such a reaction leads us to believe that the distinct behavior witnessed by LY was not conducive to him making a favorable verisimilitude judgment.

The above comparison thus suggests that different observations of the very same simulation may lead to opposite conclusions.

Deceleration of the disk

One of the cues used by subjects – the disk's slow deceleration – 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 subjects' perceptions regarding simulated residual friction (the cause of the disk's deceleration) 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 subjects to say that the disk's deceleration was due, at least in part, to residual air 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 [30], 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, and he also made comments which would indicate that he was not aware of the existence of residual friction working against the disk's motion.

All the other participants associated the disk's deceleration with non-zero friction, as we had expected. It is true that the textual explanations in the multimedia *Presentation* document (consulted by *most* subjects before they made their judgment regarding the deceleration) begins by stating that the user "will have the possibility to observe and analyze an object's motion on a surface with very little friction." Subjects who paid attention might have rightly inferred that the mention of *very little* friction entailed the inclusion of *some* friction in the simulation. Observe, however, that subject KX linked the deceleration to air friction even *before* he viewed the *Presentation* document. Also observe that subject FS, who had consulted the document, still did not expect that residual

[30] DQ was not the only subject to have launched the disk while the merry-go-round was rotating, but the only one to attribute the disk's deceleration to rotation of the merry-go-round.

friction would be included before he initially launched the disk. Hence, the textual explanations cannot be held completely responsible for the effectiveness of this cue, in all circumstances.

Turning to another issue, we observed that the *rate* of deceleration was *detrimental* to verisimilitude for one subject (ER). Although subject ER did acknowledge the presence of friction working against the disk's motion, he felt that the disk *was not slowing down fast enough*. This lead him to believe that air friction had been included in the simulation, but that residual friction *due to the table's surface itself* had not been included.

ER had had actual experience using another type of air-table, on which the metal disk he used (as opposed to the VPLab's simulated plastic disk) may have behaved quite differently. We believe that his prior experience with this type of air-table was an important factor contributing to the disk motion's lack of verisimilitude. Nevertheless, it cannot be said that this was the sole factor because another participant, subject CP, also had made prior use of such a table and did not find fault with the rate of deceleration. It seems that CP's judgment was opposite to ER's because:
(1) CP was very aware that there was a difference between the apparatus he had used previously and the one that was simulated ; and more importantly, (2) CP recognized that this difference had an impact on the disk's behavior:

> ***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 subjects judged the disk's deceleration. The first is that a simulated behavior for which designers have high expectations in terms of contribution to verisimilitude, may be effective for several individuals, as shown by the positive reactions of most subjects. Others, however, might not react favorably, as shown by the negative reaction of ER (who found fault with the rate of deceleration). 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 attribute different causes to this same 'normal' behavior (at least, during their first contacts with a simulation). 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 residual friction in the simulation.

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

Random fluctuations

Random fluctuations of the merry-go-round's angular velocity (rotational speed), as well as the effects of vibrations of the merry-go-round's structure, had been included in the simulation model in order to enhance its fidelity to the actual apparatus. As these elements were not detectable, we cannot say whether they would favor verisimilitude, but we can say that they were not expected by subjects. Nonetheless, it is possible that knowledge of the inclusion of such fluctuations could promote credibility. This topic will be discussed in a further section.

4.5. General visual presentation and graphical attributes

In this section we examine judgments regarding the simulation's general visual presentation and graphical attributes. Our first task will be to discuss a topic closely related to judgments of the simulation's behavior, which was the topic of the previous section. The question of the appearance of the measuring instruments will be addressed in a further section.

Connections between judgments concerning graphical attributes and those regarding the simulation's behavior

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 subjects illustrates this capacity very well. When watching the disk's jerky motion [31], as it was supposed to move extremely slowly, both subjects AN and ER proposed that the software did not allow for smooth presentation of the motion and that the jerky movement was really representing slow movement. 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) was poor but *where credibility was in fact preserved*.

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

Subject FS's perception that the Manipulation workspace's graphical attributes were "attractive" and "game-like" lead him to expect that residual friction would not be included at all in the simulation. Here, his judgment started with perception of graphical attributes (attractive), which probably lead him to imagine appropriate target users (beginners), and then to anticipate the simulation's level of complexity (simple). For the same reasons, FS also seemed to feel less involved in some tasks like uncertainty assessment.

Both subjects LY and BO had an opposite attitude. When LY was asked if he felt the same as FS, he answered that there "wasn't really a relation between content" and graphical quality.[32] As for subject BO, though the simulation's graphics also reminded him of video games (like subject FS), 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.*

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[31] This effect was not the result of the physical model of the disk motion. Instead, the disk's jerky motion (when extremely slow) was unintentional and caused by intrinsic display limitations.

[32] What's more, after having been asked if he had previously played realistic video games, LY made the following statement:

> *[The VPLab] is somewhat like SimCity [the videogame]* ***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*.

BO later added that possible lack of credibility didn't have much to do with graphical attributes. 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.

Other verisimilitude judgments concerning graphical attributes and visual presentation

We have just seen, in the above excerpt, that subject BO seemed satisfied with the VPLab's graphics. Other subjects (e.g., CP) also had praise for the VPLab's visual presentation.

Still, others had a more negative reaction (e.g., AN, ER, FS). Subject ER was the participant who was 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 [33] 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 in a narrow space 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 designer's 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". We must note, however, that this subject praised the VPLab for its "attractive" graphics – in comparison to 'home-made' 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 usually encounter in their science classes. However, some of these same individuals (e.g., FS), or others (e.g., AN, ER, JW), may feel that those graphical attributes could or should still be improved in order to further promote presence or credibility. It would be interesting to verify whether these types of negative judgments concerning graphical attributes similar to those of the VPLab arise from comparing software like the VPLab to more graphically complex computer applications (e.g., highly realistic video games). Neither AN, ER, nor JW reported playing realistic video games (only FS reported having done so), but most of these subjects had *seen* such video games before.

4.6. Objects, operations, and data

In this section, we present judgments pertaining to objects present in the VPLab environment, focusing on the tools and instruments, the operations performed with these, and the type of data that can be collected. Additionally, we discuss how subjects perceived the handling and behavior of measuring instruments.

[33] The simulations in both the Manipulation and Analysis workspaces use specific color schemes comprised of vivid hues: 'warm' colors (i.e., red, yellow, orange) for the Manipulation workspace simulation and 'cool' colors (i.e., colors towards the blue/violet end of the spectrum) for the images displayed on the Analysis workspace monitor.

Virtual instruments, operations performed, data collected

A number of subjects (e.g., CP, IV, KX) felt that the same kind of data could be collected within the VPLab as in a real lab.[34] 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.*

Some of the instruments – the virtual ruler and protractor (see fig. 2) – seem to have been perceived by many participants as objects that could be found in a lab. Other instruments with less 'conventional' appearance, especially the virtual tape measure (see fig. 3), were perceived more negatively by a number of subjects (e.g., AN, ER, MZ). In the case of the tape measure, the digital display and the red 'tape' (which actually looks very much like a string) were judged 'unrealistic' by some.[35] Furthermore, certain participants (e.g., IV, MZ) mentioned that in an actual lab, it would be more practical to use a ruler or another type of tool to measure lengths, rather than a tape measure.

For one subject (ER), verisimilitude was considerably affected by the presence of certain instruments in the environment. This subject was really bothered by the fact that instruments which he perceived as "real" (the stopwatch, protractor and ruler) shared the environment with others which he perceived as "unreal" (the calculator [36] and tape measure). We believe that objects which were similar to those the subject had seen, appeared more real to him than those which weren't, and that dissonance or lack of coherence occurred because both types of instruments were present in the same space. What's more, this participant further complained that "all the gadgets" were distracting him from what he really should be doing– that is, from studying the real phenomenon.

Another subject (GT) stated that the type of instruments available, as well as the way they looked and the way they were controlled, made the VPLab look and feel like a video game. For this subject, however, "looking like a video game" had the connotation of "being very realistic":

> *In video games, we often see this – a logbook or a camera. [The VPLab's camcorder] is designed in a very real… very realistic way: you can almost manipulate it… with your fingers. You click on a button with the finger [i.e., hand-shaped cursor] and it closes [the camcorder's screen] automatically. So it's very realistic, it's* ***gadgety*** *[…] You don't enter functions with the keyboard – it's almost always done with the mouse and a hand [i.e., hand-shaped cursor] on the screen.*

Handling and behavior of the measuring instruments

Some participants felt that the measuring instruments could not be handled as expected or that they behaved in a strange fashion. For example, a number of subjects (e.g., IV, ER) were considerably displeased that the virtual ruler and protractor did not allow for arbitrary rotations, but were restricted to 90-degree turns. It would have been more "realistic" and satisfactory for these

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[34] Furthermore, using traces of the disk – specifically in the form of *dots* – as data was a cue which gave rise to verisimilitude for several subjects (e.g., BO, CP, ER, LY, MZ).

[35] Also, the tape measure's 'inner workings' seemed very difficult to explain. One reason is that the measurement starts at a red circle drawn on the tape measure's plexi-glass casing ; some participants (e.g., AN, MZ) said that they could not figure out how the measurement would be processed by the tape measure if it were to be replicated exactly in reality. In addition, its tape (which was instead perceived as a string) "seemed to come out of nowhere".

[36] The simulated calculator does not have buttons. Instead, mathematical expressions are entered into it using the keyboard. It is rectangular but, contrary to most pocket calculators, its width is twice as long as its height.

subjects if they had been able to smoothly rotate these tools just by 'dragging' a corner in a circular motion.[37]

Judgments toward the tape measure's behavior were not the same for all subjects and appeared to be very complex. Some participants (e.g., ER) felt that the tape measure's components behaved quite differently from their real counterparts.[38] For one subject (LY), an important cue leading to lesser verisimilitude was his perception that the tape measure was not as intuitive to use as its real counterpart. This participant had not been able to find the device's reference points for the beginning and the end of the measurement.

Nevertheless, other subjects (e.g. FS, IV) had a more positive view of the tape measure. In particular, subject IV elaborated at length on this topic, revealing just how complex judgments toward certain instruments can be.

At a basic level, IV judged that the virtual tape measure provided the same type of data that he expected to obtain in an actual lab. At another level, and in contrast to other subjects (e.g., ER, LY), subject IV enjoyed using the virtual tape measure and said that its "way of functioning" was the same as for "a real tape measure". This was probably because mappings of mouse-driven actions to hand-driven actions (those possibly performed with one's hands when manipulating an actual tape measure) were thought to be satisfactory– i.e., manipulating the same types of components seemed to produce the same types of effects.

At yet another level, IV said he would never use the virtual tape measure's real-world counterpart in an actual lab because it could never be manipulated with as much precision as what was provided through mouse-driven actions in a 2D space. However, the subject also stated that *some* imprecision remained despite this 'excess in precision' and this preserved verisimilitude, to some extent.

Thus, IV's case suggests that there can be more than one dimension to verisimilitude judgments concerning virtual objects like the tape measure. As in the case of the VPLab's main metaphor, the divergence of judgments regarding such virtual objects as the tape measure is linked, in our opinion, to the fact that common experience or awareness of their intended referents (or of very similar objects) was not shared by subjects.[39]

4.7. The criterion of precision and the assessment of uncertainty of measurement

For several participants (e.g., CP, GT, HU, IV, KX, MZ), precision was 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

[37] At the time of the study, this feature was not feasible due to software limitations, but it has since been implemented.

[38] Subject ER said that the virtual tape measure behaved differently from a real one because:
1 - Once the tape was deployed, the casing could be made to rotate fluidly around the ring at the end of the tape (which was then stuck in place to be used as the first point of reference for the measurement).
2 - The subject did not expect to use the red slider (on the side of the casing) to immobilize the ring and move the casing around it– instead, he felt that this type of slider usually has a different function on a real tape measure (locking the tape into place when its length is sufficient).

[39] It is interesting to note that tape measures with digital displays do exist and are sold commercially but are less common than the older models that most people use at home. In any case, the virtual tape measure's digital display is not the only feature that a number of subjects felt was different.

of experimental work: during the preliminary interview, certain subjects (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.

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 precise tools, and among them, engineering students probably had the most prior contact with high-precision instruments. It is entirely possible, however, that precision would be of much less importance, as a criterion for verisimilitude judgments, in the case of individuals having little experience with actual laboratory instruments and practices.

With this in mind, let us investigate judgments involving precision. We shall see that precision of the VPLab's virtual tools was appreciated in a wide variety of ways.

Precision of the virtual instrument vs. precision of the object it appears to represent

Sometimes, an instrument's precision was judged with reference to the actual physical object that the simulated tool was meant to represent. For instance, a number of subjects (e.g., HU, LY, KX) felt that the virtual protractor was *less* precise than its real-world counterpart ; this had a considerable impact on its verisimilitude. The following excerpt is an excellent illustration. During the debriefing interview, subject HU rated the probability of finding the VPLab's protractor in a physics lab at 2 on a scale of 1 to 5 (with '1' meaning a very low probability and '5' meaning a very high probability). He gave the following explanation for this rating:

> *The protractors that I've used before had a calibration that was [detailed] to the one-degree mark. We would really see the one-degree mark… so the level of precision [of those protractors] is a bit higher [than that of the VPLab's protractor]. So this one may not be precise enough. I would say "2" - a low probability […] because it's not precise enough for a physics lab.*

Demonstrating an opposite reaction, some subjects (e.g., LY, IV) felt that another tool – the virtual tape measure – could yield *greater precision* than the object which they perceived as being its real-world referent. Subject LY, for instance, could not imagine himself measuring a short distance with sufficient precision (in an actual lab) with what appeared to be a string (the virtual tape measure's 'tape').

Precision of virtual instrument vs. precision of an object other than its apparent referent

An instrument's accuracy could also be judged with reference to the level of precision that a user expected to obtain for the *type of data* provided, or with reference to other types of real-world instruments providing the same data. For instance, subject DQ judged that the tape measure was precise enough because it seemed to provide the same level of precision as a ruler. Judgments may not always go the same way when this type of criterion is applied however: contrary to DQ, subject HU felt that the measurements would have been more precise, had he been able to use a ruler for all measurements, instead of the tape measure.

In slight contrast, one subject (ER) expected more precision from the tape measure than it could yield because he had a vague recollection of being able to obtain 'more decimals' for length measurements (in similar experiments). For this subject, however, another factor was of influence: the tape measure's digital display (see fig. 3) seemed to create expectations for a very precise reading. This is quite interesting, as many subjects referred solely to other types of devices with digital displays (e.g., voltmeters) when assessing uncertainty of length measurements performed with the tape measure. Indeed, users can make associations based on a particular aspect (in this case, the digital display) of a virtual object which evokes their past experience with other objects (in this case, a voltmeter) that can be considered quite different.

Precision of virtual instruments vs. precision of software tools, and other concerns regarding uncertainty of measurements

When discussing the precision of the virtual instruments or the assessment of uncertainty of measurements, subjects sometimes referred to other computer software which they had previously used (e.g., Computer Aided Design [CAD] packages, Graphics creation software).

In one case, 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:

> *[…] 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.*

This subject's reaction is understandable, insofar as the act of measuring had always implied great precision for him– precision and methods available with software tools he had frequently used, and precision which had been required of him in the course of his past employment as a parts inspector in the field of aeronautics.

Some participants, like subjects CP and ER, had mixed reactions when they were asked whether it was surprising to be required to assess uncertainty of measurement while working with the VPLab. For CP, dissonance resulted from working on "*physics* software" like the VPLab which allowed for much less precision than that which is usually available in most computer-assisted tasks. This subject also felt that he couldn't get as close to the measuring instrument (the ruler) as he wanted, 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 visual alignment of tools on objects being measured. CP did acknowledge, however, that uncertainty assessment was a normal part of physics experimentation.

For subject ER, their was an even more important tension between usual 'computer precision' and measurement uncertainty, specifically related to the virtual tape measure. Dissonance was created because, on the one hand, it was necessary to align the tape measure's components with the object that was being measured, and on the other hand, the reading of the measurement was obtained on a digital display within a computerized environment:

> *Well, it's because [the tape measure] is between… Because, given the fact that [the VPLab] is a computerized system, you tell yourself that it is going to measure precisely – direct, precise, real values. But this is rather somewhere between taking precise values and taking values that refer to something that would be collected manually. So because it's between the two, I'm having a bit of difficulty…*

Interestingly, assessing uncertainty when using the virtual ruler was not problematic for ER.[40]

Other subjects (e.g., HU, IV, KX, LY) exhibited more approving reactions regarding uncertainty of measurement. Such a reaction came from subject LY who, contrary to subject GT, commented favorably on the absence of a CAD-like 'snap' function which would have allowed the

[40] This excerpt also goes to show that some individuals like ER give the impression, through their judgments, of being in a metaphorical 'state of limbo', as they are 'caught between' aspects of the virtual environment that seem real to them, and other aspects that seem unreal or artificial.

user to fix the protractor 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 – 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, even when it came to measurements obtained with the tape measure; this is in direct opposition to ER's attitude toward the tape measure.

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 subjects to assess uncertainty if the interface, and more specifically the measuring instruments, afford it.

As a matter of fact, at least two subjects (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.*

Some judgments involving the criterion of precision had nothing to do with the virtual measuring instruments, per se. For instance, subject MZ felt that the VPLab's instruments were precise enough but that the metaphor itself (and its *Trace* function) did not provide adequate precision:

> *[…] if you're going to film [the experiment], you might as well arrange it so you can get good resolution ; you'd get a close-up of the table in order to obtain a better image, for instance … You'd arrange to fix a grid on the table's surface so it would be easier to evaluate distances. It seems to me that these are things you think of almost naturally when you're doing it for real, whereas in [the VPLab], there are big limitations.*

This sensation of lack of precision occurred, as mentioned before, when MZ realized that the recorded image's quality degraded as he zoomed-in to measure distances between traces more precisely. He judged this apparent lack of precision in terms of the accuracy that was usually available when using computers, and thus regarded the resulting uncertainty of measurement as an unnecessary consequence of poor visual rendering. MZ perceived uncertainty as being artificial:

> *I'm aware that this aims to simulate the manipulation [of instruments] but… I know that the computer is powerful enough to give me dots [i.e., position of traces] which are much more precise than this. So this is a kind of false uncertainty. It's just that the dots are too big… In reality, I'm certain that the computer knew very, very precisely where the dots were when it made them.*

The above discussion (and the beginning to 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 indicates 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).

4.8. Freedom/Control within the simulated environment

Precision was also important to a number of subjects who made judgments in regards to manipulation of the disk on the air-table. Several subjects (e.g., BO, GT, HU, IV, KX, MZ) spontaneously complained about lack of precision when launching the disk. For instance, subject GT claimed that in a real lab, one could know what force had been applied when launching the disk with the "elastics" that line the table's sides. This is something that he had not been able to do with the VPLab. GT also seemed to say that the initial position of the disk before its launch would not be as precise in the VPLab's simulation as in an actual lab.

In contrast, another subject (FS) made comments which indicate that he *approved* of the level of precision afforded by handling the disk with the mouse and cursor (when compared to launching a real disk with one's hands on a real air-table).

Although as we have seen, some participants complained about the level of precision available when handling apparatus, some of those same subjects and others (e.g., BO, HU, FS) were satisfied with the available level of interaction provided through 'direct manipulation' with the mouse and the hand-shaped cursor (e.g., drag and drop of apparatus components).

For those subjects, 'free interaction' with objects [41] and freedom to chose 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 which 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. One example of this is the possibility of varying the number of *Traces* and the interval between them – this freedom contributed to the overall verisimilitude of working with the VPLab, for HU, since it empowered him to choose his own method:

> *I do everything, basically. See here: I determine the number of dots [i.e., traces] and the interval [between them] myself, as I want… 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.*

[41] Recall that interaction with VPLab objects is not '*totally* free' (at least, from the designers' view-point), insofar as many 'real-world' constraints have been included in the environment.

In this section, we have presented evidence which indicates that, for certain individuals, perceived control over objects and perceived limitations in regards to interaction are significant issues with respect to verisimilitude.

4.9. Anticipated pedagogical objectives as frameworks for credibility judgments

An interesting yet somewhat unexpected finding of this study is that subjects sometimes tended to use potential pedagogical objectives – those which they anticipated as being eventually set for students using the VPLab – as general frameworks for credibility judgments.

One example of this process involves subject LY. Previously, we mentioned that this subject commented favorably on the absence of a function which would have allowed the user to fix the protractor very precisely on the object being measured and automatically obtain a measurement. He argued that such an automatic function would be detrimental to students in a context where learning how to conduct a lab experiment is more important than getting excellent results (and this is the context he anticipated for use of the VPLab.) LY's main impression was that performing measurements oneself without the help of an automatic function was favorable in that context.

Another important issue in this area deals with the question of the type of target users that were anticipated by subjects. We observed that some subjects (e.g., FS, MZ) judged that the VPLab was destined to be used by students of lower grade levels than their own; occasionally, this seemed to have an impact on their credibility judgments: for one participant (FS), lower simulation fidelity was *expected* and deemed adequate for *less advanced students*. Another subject (KX) felt that the VPLab would serve as a very good surrogate when used by *students who do not have access* to an actual lab, but he thought that *students with access* to a school lab should use it rather than the VPLab. He argued that students would understand and learn more if they could do the experiment "concretely" in an actual lab.

The cases discussed above strongly suggest that users who only know about the VPLab's general purpose (i.e., to teach experimental physics) can form relatively specific representations of designers' goals when working in the simulation-based environment which they created (and when following very basic task scenarios consistent with the designers' vision for use of the environment– admittedly, these are exogenous to the environment itself) ; we have indications that these representations can then serve as frameworks or criteria for credibility judgments. Indeed, the anticipated context of use seems to underlie credibility judgments in meaningful ways.

4.10. Potential anomalies and use of discursive cues (i.e., explanations)

As we discussed in a previous section (*The question of ontological status*), a number of subjects (e.g., ER, GT, IV, KX) expected ideal or optimal experimental conditions within the VPLab. Many associated computers, in general, to 'perfection' and to 'consistent' behavior, and did not expect computer programs to spontaneously generate errors. Hence, many also did not expect simulated experiments to present anomalies or degraded experimental conditions similar to those which can show up in school-lab experimental set-ups (e.g., a gust of wind blowing on the disk, dirt on the air-table's surface).

Additionally, some participants (e.g., CP, LY, MZ) also felt that it was impossible, when handling the simulated apparatus, to commit serious errors which would radically affect experimental outcomes (e.g., launching the disk too abruptly and damaging it).

When subjects were eventually told that it would be possible to simulate the types of degraded conditions or random fluctuations discussed above, some (e.g., CP, ER, MZ) said that it would not be possible to detect these, even if they did exist in the simulation.[42] Others (e.g., IV, HU) questioned the usefulness or pertinence of simulating such elements. For instance, subject HU claimed that simulated anomalies were unwarranted, as the goal of the experiment was really to study and understand the disk's motion (read 'normal' motion), and not to be confronted to 'tricky' situations. Furthermore, he felt that some of the potential anomalies and random fluctuations of real experimental set-ups could be avoided by manufacturers of apparatus (and sometimes even by students), if they really wished to do so. For this subject, credibility was rather linked to the replication of as many conditions *as are 'inescapable'* and *'useful'* in reality.

In slight contrast, other participants (e.g., BO, JW, KX, LY) said right away that the inclusion of anomalies would improve the simulation. For example, when subject KX was made aware (by the interviewer) that experimental conditions could involve randomness, anomalies and the possibility of committing serious handling errors, he stated that this would be very good as it would truly be a "model of a real situation". The crucial point here is that these subjects (as well as others) also mentioned that users *should be warned* of the inclusion of such anomalies. Hence we see that discourse – in this case, explanations regarding the simulation's model – would play an important role with respect to verisimilitude judgments in this context. For some students like subject KX, potential cues which would allow detection or awareness of experimental conditions involving random fluctuations of parameters or anomalies in the simulated apparatus may give rise to enhanced verisimilitude.

We already have a few indications that *discursive* cues can matter when it comes to credibility judgments concerning the simulation's complexity. Recall that we have previously discussed the importance, for credibility, of viewing the video clip which included verbal discourse. In addition, we can point to other cases involving the *textual and graphical* explanations in the multimedia *Presentation* and *Explanation* documents.

The most convincing of these cases concerns subject LY. During the session, this participant did not seem to mind that one of the simulation's behaviors which he had observed (slow deceleration of the disk due to presence of residual friction on the table's floor) pointed to greater complexity of the simulation, while another observed behavior pointed to lesser complexity in the collision model (he had deemed that the sides of the table were perfectly uniform). For LY, this contradiction (if ever there actually was one) had been resolved by the explanations in the multimedia *Presentation* document which made things coherent: the subject had noticed that '*minimized friction* on the table's surface' was mentioned in the *Presentation* document whereas no reference had been made in regards to the table's sides (hence, in the subject's opinion, designers had no obligation to make the table's sides 'less than perfect').

The multimedia presentation of the experiment seemed to set the tone for LY's expectations of complexity and this was linked to his prior experiences in situations where teachers had announced, before specific experiments, that certain aspects of the physical phenomenon under study would not be taken into account.[43]

Still in LY's case, yet another very important *discursive* cue could give rise to credibility: extensive mathematical and theoretical information accompanying the simulation. The subject felt

[42] Subject MZ also said that it did not seem possible to make adjustments required to correct these defects, hence students should not be expected to anticipate them.
[43] LY probably associated the act of neglecting these aspects at the time of analysis (in order to simplify the process), with the act of neglecting these aspects when designing the simulation itself.

that greater disclosure of the ‘inner workings’ of the simulation (in the form of mathematical and theoretical information) was preferable. During the debriefing period, the interviewer showed LY theoretical explanations (in the *Explanations* multimedia document) which contained animations of the disk’s motion (including items such as vectors). LY stated that this type of information would promote credibility of the Manipulation workspace simulation.

We believe that LY’s expectations in regards to mathematical and theoretical descriptions of the simulation’s behavior were conditioned by his prior experience with simulations created with MAPLE ™ software: it seems that these visual simulations had been accompanied by real-time exposition of the formulas and calculations used to render them. This case suggests that disclosing the method through which a simulation model is constructed could, in some cases, enhance credibility of simulated environments (to the extent, of course, that the method would be perceived as valid).

As a concluding note pertaining to discursive cues, it seems significant that we did *not* observe any judgment involving a lack of credibility of information (Tseng and Fogg, 1999a, 1999b) contained in the multi-media documents– i.e., the video clips, the textual information, and the animations. It is entirely possible that *this* type of information will not be subject to substantial doubt, or so at least when it is assumed to be provided by authority figures like teachers and domain experts.

5. CONCLUSIONS

In this work, we devised a method aimed at probing users’ perceptions in regards to the credibility of a simulation-based environment. This approach has proven to be 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 specific cues in the environment could play different, even contradictory, roles in the formation of said judgments. We also found that, in some instances, *unfavorable* assessments could be promoted by cues which designers initially expected to *favor* verisimilitude. Furthermore, our descriptive approach allowed us to begin confirming that individual traits, such as certain attitudes and prior experiences, can be very significant in the expression of particular judgments.

5.1. Specific conclusions

As far as our subjects were concerned, some of the prevalent individual traits of which we have just spoken included *a priori* attitudes toward simulation, prior use of certain computer applications, knowledge/experience of specific apparatus and related subject matter, and knowledge/experience of lab work in general. Indeed, it is especially noteworthy that some verisimilitude judgments seem to be at least partially based on preconceived ideas or prior experience pertaining to the medium of simulation itself.

As mentioned above, the question of presumed credibility, which is linked to *a priori* trust in simulation as a medium, may be of particular interest to researchers and practitioners. First, our data indicate that students’ *a priori* attitudes toward simulation as a medium can be unfavorable, neutral, or even favorable. Second, we have indications that unfavorable *a priori* attitudes may influence verisimilitude judgments related to the constructed/virtual nature of synthetic environments. We have established, however, that some users will make these types of judgments and will *still* express other types of judgments *in favor* of overall credibility. In essence, these elements have also contributed to the validation of our verisimilitude concept.

Another high-level issue was related to the VPLab's main metaphor. Some of the technical processes and objects represented by the metaphor were unfamiliar to subjects (with respect to their experience of a laboratory context), and this may have caused certain user interpretations of the metaphor to stray from its intended meaning; in some cases, such interpretations apparently lead to negative effects on verisimilitude. We proposed that more 'familiar' metaphors could possibly give rise to less divergent and more positive verisimilitude judgments– to the extent, though, that a hypothesized 'latency of favorable judgments' would not impede their expression in 'everyday conditions'.

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-word constraints (e.g., a moving object's deceleration signifying inclusion of friction) often lead to favorable credibility judgments (although this is not always strictly the case) .

In a related area, we concluded that use of video clips (showing the actual phenomena replicated by simulations) was a valuable asset 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 common 'referents' in the form of video data. 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/graphical presentations and theoretical explanations of the simulation, also seem to have had an impact on verisimilitude judgments expressed by certain participants. Following such a research trail, investigators could explore the consequences of disclosing information to users concerning the 'inner workings' of simulation models (an act which some might regard as more ethically correct– see below). 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 subjects would be made aware of simulation modeling methods and informed of unapparent 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 regularly informing users that the designers "have done their homework".[44]

[44] A similar test could be conducted for virtual lab metaphors by informing users of relationships between metaphors and analogue experimental methods used in real labs.

5.2. Outlines for future research

For future research, we recommend that simulation verisimilitude 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 are not 'confined to a closed box': they 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 (c.f. Tseng & Fogg, 1999a). The context of our study did not allow for the investigation of these social aspects.

Furthermore, our investigation was conducted in a research facility rather than in the user's usual work–setting (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. When dealing with students for instance, efforts should be made to observe verisimilitude judgments in class (or at home, in the case of distance education). 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.

Attitudes resulting from prolonged use of simulation-based environments (*experienced* credibility) should be given very special attention. 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).

Another promising but as yet unexplored area for research deals with possible links between simulation credibility and the level of *attention* given to relevant cues. For instance, it could be useful to test whether users who pay much attention to cues thought to favor verisimilitude (relevant discursive cues, for example) find simulations more credible than others who do not. Once verified, this hypothesis would have interesting implications: should there be a strong link between attention to cues and credibility, a designer's power to influence credibility would then be somewhat more limited than could otherwise be expected, insofar as user attention is difficult to control in everyday conditions.

We have 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.[45]

Obviously, we cannot claim to have statistically demonstrated the existence of consistent causal relationships between verisimilitude judgments and individual traits; certainly, this should be the

[45] Recall that while our sample was sufficiently heterogeneous, it was also exclusively composed of students that had volunteered for participation to the study.

focus of future studies. Nevertheless, we believe that our observations can serve as excellent basis for such investigations involving simulation-based science laboratories. Such studies could focus on the following types of user characteristics: [46]

– interests, attitudes, aptitudes, and experience pertaining to lab work in general ;
– knowledge of subject matter pertaining to specific simulations ;
– exposure to computers, multimedia applications and simulation ;
– *a priori* attitudes toward simulation and computers in general ;
– 'computer confidence', computer expertise, and knowledge pertaining to computers and simulation.

5.3. Ethical considerations

Finally, let us briefly explore another very important aspect which may be too hastily overlooked by members of the simulation research and development community: that is, ethical issues associated to how verisimilitude and credibility are promoted.

First, we believe that caution toward simulation, in some measure, is a commendable attitude, as is caution toward information provided through *any other* medium. It could be argued, however, that for *certain* users, *a priori* distrust of simulation goes beyond that which can be deemed 'healthy skepticism'. Still, in the case of simulated lab work, one could question the very notion that something truly unique is going on when students are skeptical of such simulations. As Hennessy and O'Shea (1993) put it : "*It must be recognized that the same concern regarding simulation credibility can be applied to laboratory work […] After all, the science laboratory is another idealized situation*." This suggests that the *credibility* of the simulation's referent *itself* should also be pondered.

In any event, when dealing with credibility of media, it is appropriate to consider the means through which knowledge and beliefs might be influenced. For instance, one may feel that using video footage of real apparatus, with the *sole* purpose of promoting credibility of simulated experiments, would not be an ethically correct solution as it would rest, at least to some extent, on the premise that students should trust video data without much reserve. [47]

More generally, it is obviously unethical to make simulations appear to unsuspecting users as being more realistic (i.e., as having higher fidelity) than is actually the case. Nevertheless, designers and practitioners should still strive to make simulations with partial fidelity seem credible, when those simulations can be deemed valid and useful by designers' peers and domain experts. However, this should *never* be done to the detriment of users.

[46] Some of these items are inspired by a review of user variables relevant to general computer credibility (Tseng and Fogg, 1999a, 1999b): namely, *user familiarity with subject matter, user understanding of computer system*, and *user need for information.*

[47] As such, we recommend that practitioners who use video clips allow users the opportunity of evaluating the trustworthiness of the video footage itself by providing them with at least some of the following items, while stressing their relevance: the opportunity of verifying the video producer's credentials ; information about when and where the footage was shot ; a detailed description of the objects depicted in the video footage ; a description of special circumstances that significantly affect the behavior of apparatus, but are not obvious in the video clip ; information regarding manipulation or special editing of the footage ; other video footage from different sources.

Note that enhancing credibility is *not* the sole purpose of including video clips in the VPLab. Among other reasons, excerpts of professionally produced science videos are used because they contain well presented theoretical explanations and real-life applications of phenomena involved in the VPLab's experiments.

In instructional simulations, *voluntary* departures from total fidelity can be very beneficial (Alessi, 1988) – when such is the case, it can be explained to users easily enough. In addition to this, we strongly insist that designers should strive to uncover any significant *involuntary* departures from total fidelity, as well as barriers to the achievement of valid objectives which may be pursued by users. What's more, it is imperative that this information be disclosed to users themselves, even if one should do so only after they have finished using a simulation. People should *never* come away with a false impression that, in the course of using a simulation, they have acquired specific knowledge or skills, or accomplished particular objectives, when that is actually not the case. We argue that as a general rule, users should also be provided with information concerning the workings of underlying models and modeling methods. Not only is such disclosure ethically correct but, in the long run, it may also help promote more widespread confidence in simulation as a 'trustworthy' medium.

Acknowledgments. First and foremost, we wish to express our 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. We also wish to 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.

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

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APPENDIX A: INDIVIDUAL SUBJECT PROFILES

In section A.1, we describe some of the types of information used in subject profiles. In section A.2 we describe each subject's profile in detail. This serves two purposes: (1) exposing a more thorough description of our sample and (2) exposing data which will be useful for a deeper understanding of individual results for each of the subjects (much like socio-demographic data in other types of studies).

A.1 Data used in subject profiles

This section exposes some of the data used to describe each subject's profile. First, we present information about subjects' self-assessed attitudes toward computer use, in general. Second, we present self-assessed computer expertise. Third, we present information concerning use of simulation as well as multimedia applications bearing similarities to the VPLab. Finally, we present information regarding subjects' *a priori* attitudes toward simulation as an educational medium.

Again, note that our purpose here is not to expose this information so it can be analyzed itself as stand-alone data. Instead, we wish that the reader use it as reference when reading our study's results (and especially the accounts of individual cases in Appendix C).

A.1.1 Self-assessed attitudes toward use of computers

Computer-related attitudes are considered as factors affecting "both the extent and the manner in which students use computers." [48] The context of our study made it impossible to use a lengthy, valid and reliable questionnaire just to assess these attitudes. We cannot therefore claim to have *measured* them.

Nevertheless, we were able to acquire data of a different nature which will help to describe the profiles of some of the subjects. Information in table A.1 was obtained in the course of a preliminary telephone interview by asking subjects to rate use of computers, in general, on the following 5-point scales: [49]

A) 1- Unpleasant **to** 5 - Pleasant

B) 1- Useless **to** 5 - Useful

C) 1- Difficult **to** 5 - Easy

Table A.1 thus shows data relating to **self-assessed** attitudes toward use of computers in terms of perceived (A) *pleasantness of use* and (B) *usefulness of computers*. It also shows perceived (C) *ease of use* in a column separated from the others: some authors [50] have suggested that *computer self-confidence* – i.e., belief in one's own ability to operate successfully with computers (which these authors measured principally through a scale involving items very similar to our *'perceived ease of use'*) – should be treated

[48] See Levine, T., & Donitsa-Schmidt, S. (1998). Computer Use, Confidence, Attitudes and Knowledge: A Causal Analysis. *Computers in Human Behavior*, 14 (1), 125-126.
[49] French versions of these scales were used during the telephone interview.
[50] See Levine & Donitsa-Schmidt (1998) cited in footnote 1.

separately from other computer-related attitudes. These authors could not definitely conclude, however, that *computer attitudes* and *self-confidence* were different psychological constructs.

The meaning of symbols is explained in the area beside table A.1. Observe that none of the subjects gave the lowest rating (‘1’) on any of the scales and that ratings are relatively high for most subjects. This could be due to the fact that participants were recruited on a voluntary basis within a population of individuals who use computers, most likely, for many hours a week (see table A.5).

Table A.1 Self-assessed attitudes toward use of computers.

Subjects	Perceived pleasantness of use	Perceived usefulness		Perceived ease of use
AN (chem.)	o o	o o o		o o o
BO (chem.)	o o o o	o o o o o		o o o o
CP (chem.)	o o o o o	o o o o o		o o o o o
DQ (chem.)	o o o o	o o o o o		o o o
ER (chem.)	o o o	o o o o o		o o o o
FS (eng.)	o o o o o	o o o o o		o o o o o
GT (eng.)	o o	o o o o o		o o o
HU (eng.)	o o o o o	o o o o o		o o o o o
IV (eng.)	o o o o o	o o o o o		o o o o o
JW (phys.)	o o o o o	o o o o o		o o o o
KX (phys.)	o o o	o o o o		o o o o o
LY (phys.)	o o o o o	o o o o o		o o o o o
MZ (phys.)	o o o o o	o o o o		o o o o o

Meaning of symbols

Pleasantness
o ==> o o o o o
1-Unpleasant 5-Pleasant

Usefulness
o ==> o o o o o
1-Useless 5-Useful

Ease of use
o ==> o o o o o
1-Difficult 5-Easy

One way to use this data judiciously is to look at the more extreme cases. With respect to this criterion, interesting cases include subjects CP, FS, HU, IV, LY, who gave the maximum rating (‘5’) on all three scales, as well as subject AN who gave relatively low ratings on all scales. Also worthy of mention is the case of subject GT, whose ratings vary most from one scale to the other, and the case of subject DQ, whose self-rating for *perceived ease of use* is lower than his self-ratings for perceived *pleasantness of use* and *perceived usefulness.*

A.1.2 Self-assessed computer expertise, and use of advanced operating system functions (self-reported)

Initially, we had hoped to gather information on subjects’ computer expertise in regards to abilities relevant to use of the VPLab. However, obtaining objective information on computer expertise can be a complex and lengthy process. Ideally, one would have subjects perform several tasks representative of the relevant task domains in order to assess their performance.

Since we could not implement such an assessment method in the context of our study, we gathered data of an altogether different nature, not necessarily tied to *actual* computer expertise, and having more to do with how a user *perceives* his own expertise.[51] Table A.2 thus shows self-assessed expertise relating to computer use in general and also to common applications.

Information in the '**In general**' column was acquired during a preliminary telephone interview, by asking subjects to assess their own expertise relating to use of computers, in general. Information in all other columns was obtained through a written questionnaire that was filled out by participants before they used the VPLab. Subjects were asked to assess their own expertise relating to use of window-based operating systems (e.g., Windows 95, Mac OS), word processors, browsers, e-mail, and graphics creation or image editing software (e.g., Illustrator, Corel Draw, Photoshop).

The following scale was used [52]:

1 – very weak 2 – rudimentary 3 – intermediate 4 – good 5 – expert

The meaning of symbols in table A.2 is as follows:

o : **very weak** o o : **rudimentary** o o o : **intermediate** o o o o : **good** o o o o o : **expert**

Table A.2 Self-assessed expertise relating to computer use in general and to common applications

Subjects	**In general**	Window-based OS	Word processing	E-mail	Browsers	Graphics creation or image editing software
AN (chem.)	o o o	o o o	o o o	o o o	o o o	o o o
BO (chem.)	o o o o	o o o o	o o o o	o o	o o o	o o
CP (chem.)	o o o o	o o o o	o o o o	o o o o	o o o o	o
DQ (chem.)	o o o	o o o	o o o o	o o o o	o o o o	o
ER (chem..)	o o o	o o o	o o o o	o o o	o o o	o
FS (eng.)	o o o o	o o o o	o o o o	o o o o	o o o o	o o o o
GT (eng.)	o o o o	o o o o	o o o o	o o	o o o	o o o o
HU (eng.)	o o o o o	o o o o o	o o o o	o o o o o	o o o o	o o o
IV (eng.)	o o o o	o o o o	o o o o o	o o o o	o o o o	o o
JW (phys.)	o o o	o o o	o o o o o	o o o o o	o o o o	o o o
KX (phys.)	o o o o	o o o	o o o	o o o	o o o o	o
LY (phys.)	o o o o o	o o o o o	o o o o	o o o o o	o o o o o	o o o
MZ (phys.)	o o o o	o o o o	o o o	o o o o	o o o o	o o o

Notice that the '**in general**' rating is the same as the '**window-based OS**' rating for nearly all of the subjects (the exception is subject KX).

Again, we felt that it was judicious to look at extreme cases. These include subjects with a relatively high '**in general**' self-rating who also rated themselves relatively high in

[51] Whether this relates directly to the aforementioned construct of *self-confidence*, as described by Levine & Donitsa-Schmidt (1998) is debatable.
[52] For self-assessment of expertise pertaining to computer use '**in general**', the term "weak" was mistakenly used instead of "rudimentary".

regards to most types of applications (CP, FS, HU, IV, LY [53]), as well as those with a relatively low '**in general**' self-rating, who also rated themselves relatively low in regards to most types of applications (AN, ER).

In the written questionnaire, subjects were also asked to indicate how often they used four different 'advanced' functions of windows-based operating systems (creation of shortcuts on the desktop ; use of shortcut keys ; drag and drop ; software customizing functionalities like macros or changing default options). The following scale was used:

1 – very often 2 – often 3 – occasionally 4 – rarely 5 – almost never

We judged that subjects did not report considerable use of said advanced functions if they answered either "**rarely**" or "**almost never**". Table A.3 thus shows the number of functions that each subject reported using, when counted this way. It is of interest that AN, ER, GT and JW are the only subjects who did not use all 4 advanced functions. There might be an interesting correlation between AN's and ER's lower self-assessments shown in table A.2 and their reports of less frequent use of advanced functions in window-based operating systems.

Table A.3 Use of 'advanced functions' in window-based operating systems (self-reported)

Subjects	Number of advanced functions used ('very often', 'often' or 'occasionally').
AN (chem.)	**2/4**
BO (chem.)	4/4
CP (chem.)	4/4
DQ (chem.)	4/4
ER (chem..)	**3/4**
FS (eng.)	4/4
GT (eng.)	**3/4**
HU (eng.)	4/4
IV (eng.)	4/4
JW (phys.)	**3/4**
KX (phys.)	4/4
LY (phys.)	4/4
MZ (phys.)	4/4

A.1.3 Self-reports of use of simulation and multi-media applications with characteristics similar to those of the VPLab

In order to have an indication of subjects' predispositions to perceiving the VPLab as strange or novel, we sought to find out if they had used applications bearing similarities to it. Table A.4 contains a description of each subject's prior experience with software containing simulations, as reported by them during the debriefing interview. There was a wide range of prior experience among subjects: for instance, AN reported having no prior experience whatsoever with simulation, whereas IV had tried out industrial flight simulators.

[53] Observe that these are the exact same subjects who gave the maximum rating on all three scales pertaining to *positive attitudes toward computers* (see table A.1).

Table A.4 Prior experience with use of simulation (self-reported)

Subjects	Prior experience with simulations
AN (chem.)	**No prior experience**
BO (chem.)	Realistic video games ; social science simulations
CP (chem.)	Realistic video games **(no experience with simulation in an educational context)**
DQ (chem.)	SimCity *****
ER (chem.)	SimCity; Small educational program in physics
FS (eng.)	Realistic video games ; numerical (non-visual) simulation with MAPLE software ; Conception of mechanical component simulations using Computer Assisted Design (CAD) software
GT (eng.)	Realistic video games ; Conception of mechanical component simulations using CAD software
HU (eng.)	Realistic video games ; Conception of mechanical component simulations using CAD software
IV (eng.)	**Industrial flight simulators** ; Conception of mechanical component simulations using CAD software
JW (phys.)	Small physics simulation
KX (phys.)	Realistic video games **(no experience with simulation in an educational context)**
LY (phys.)	SimCity ; Highly realistic video games ; Much experience with MAPLE software
MZ (phys.)	Little experience except for software simulating motion of stars

Moreover, in the preliminary (written) questionnaire, subjects were asked to indicate how often they used these four types of multimedia applications:
– video games ;
– graphics creation or image editing software (e.g., Illustrator, Photoshop, Coreldraw) ;
– web sites containing video or animation ;
– animation software (e.g., Director, 3D studio).

The following scale was used by subjects here:

1 – very often 2 – often 3 – occasionally 4 – rarely 5 – almost never

Table A.5 presents reported use of these types of multimedia applications. We assigned **very often / often / occasionally** to a category that we named '*More*' and **rarely / almost never** to a category that we named '*Less*'. The last column shows self-reported total weekly use of computers.

Table A.5 Use of multi-media applications bearing similarities to the VPLab (self-reported)

Subjects	**Video games**	**Graphics creation or image editing software**	**Web sites containing video or animation**	**Animation software**	Self-reported weekly use of computers, in general (hours)

***** SimCity, a popular video game, is basically a simulation of a city and its problems. The player acts as mayor. This game has been praised for its realism and has sometimes even been used in educational contexts.

AN (chem.)	***Less***	***Less***	***Less***	***Less***	6 to 12 hrs.
BO (chem.)	***More***	***Less***	***Less***	***Less***	6 to 12 hrs.
CP (chem.)	***More***	***More***	***More***	***Less***	more than 12 hrs.
DQ (chem.)	***Less***	***Less***	***Less***	***Less***	more than 12 hrs.
ER (chem.)	***Less***	***Less***	***Less***	***Less***	more than 12 hrs.
FS (eng.)	***More***	***Less***	***More***	***More***	more than 12 hrs.
GT (eng.)	***More***	***More***	***More***	***Less***	6 to 12 hrs.
HU (eng.)	***Less ****	***More***	***Less***	***More***	more than 12 hrs.
IV (eng.)	***Less***	***Less***	***More***	***Less***	6 to 12 hrs.
JW (phys.)	***Less***	***Less***	***Less***	***Less***	1 to 5 hrs.
KX (phys.)	***More***	***Less***	***Less***	***Less***	more than 12 hrs.
LY (phys.)	***Less ****	***More***	***More***	***Less***	more than 12 hrs.
MZ (phys.)	***Less***	***More***	***Less***	***More***	more than 12 hrs.

Looking at the more extreme cases, we see that AN, DQ, ER and JW reported '*less'* frequent use of all four applications (with JW reporting less weekly use of computers in general), whereas CP, FS and GT reported '*more*' frequent use of three out of four applications (with CP and FS reporting greater weekly use of computers in general).

A.1.4 *A priori* attitudes toward simulation as an educational medium

Table A.6 contains indicators for subjects' *a priori* attitudes toward simulation.[56] This information allowed us to evaluate how credible simulation was to the participants, as an educational medium, even *before* they inspected the VPLab.

The left half of table A.6 contains indicators for *a priori* attitudes toward simulation **in comparison to *video***, **when used to illustrate physics concepts**. These indicators were obtained by asking subjects three questions (see Appendix B) pertaining to two different hypothetical classroom situations (a classical mechanics course and a relativity course) where a teacher would try to convince skeptical students of the validity of a counterintuitive physics concept.

The meaning of symbols is as follows: (**–**) indicates a moderately unfavorable attitude towards simulation ; (**– –**) indicates a strong unfavorable attitude towards simulation ; (0) indicates neutrality ; (**+**) indicates a moderate tendency to favor simulation ; (**+ +**) would indicate a strong tendency to favor simulation.

The right half of table A.6 presents indicators for *a priori* attitudes toward simulation **in comparison to use of *real equipment*** (though simpler than the one needed for the actual task)**, in skill training**. These indicators are related to three 5-point scale items whereby subjects expressed levels of confidence in operator trainees, in the context of two different training situations (1 - training for a low risk mechanical operation, and 2 - training for a high risk computer-based task). The meaning of symbols is the same as before.

***** During their debriefing interviews, subjects HU and LY mentioned that they had played realistic video games, as shown in table A.4. Their answers to the questionnaire might just indicate that they had not played video games very often *during a relatively short period preceding their participation in the study*.

56 These indicators are actually symbols representing categories of values ; these values can be found in tables B.1 and B.2 of Appendix B.

The questionnaire used to evaluate *a priori* attitudes toward simulation was administered purposefully to subjects before they inspected and interacted with the VPLab. Moreover, in order to verify the validity of these indicators, subjects were confronted with their answers during the debriefing period at the end of the session. In consequence, when needed, appreciation of subjects' *a priori* attitudes is revised or completed in their **profile** (see section A.2). These revisions are not presented, as such, in the table A.6 ; however, the marking ' **c** ' (in the *corr.* columns) indicates that further information contained in their profile could be taken into account. [57]

[57] Note that the reader could also choose to entirely disregard these revisions if he thought that the indicators themselves were a more accurate and 'less contaminated' reading of *a priori* attitudes toward simulation. Here are two arguments that could be put forward in favor of this:

1. With the questionnaire, we sought to evaluate ***a priori*** attitudes toward simulation and not that which would be influenced by interacting with the VPLab. Consequently, comments made during the debriefing period could be considered less valid than answers to the pre-interaction questionnaire because subjects' attitudes towards simulation might be "contaminated" by interacting with the VPLab.
2. The pre-interaction questionnaire was given to subjects in two parts (1 - **simulation** and 2 - **other media**) so that subjects could not directly compare answers to questions involving simulation with answers to questions invol-ving video or real equipment (the only way they could possibly compare is from memory, i.e. by recalling answers to some or all of the "simulation questions", when answering similar questions involving video or real equipment.) Hence, this hindrance to comparison might favor independence and focus in subjects' opinions regarding simulation, making answers to these individual questions (and the resulting comparative indicators) more valid than comments made when subjects themselves were made to compare answers during the debriefing period.

Table A.6 *A priori* attitudes toward simulation when used to illustrate physics concepts (left half) and when used for training (right half)

Questions / Subjects		Corr.	Simulation is used to convince skeptical students of validity of counter-intuitive **classical mechanics concept**			Simulation is used to convince skeptical students of validity of counter-intuitive **relativity concept**			**Corr.**	Simulation is used to train operator for **scrapyard task** (low risk / mechanical operation)			Simulation is used to train operator for **nuclear reactor task** (high risk / computer-based)		
			Convince skeptical classmates	Convince subject	Quality of method	Convince skeptical classmates	Convince subject	Quality of method		General level of confidence in operator	Operator (not) prone to commit grave errors	Operator prepared for difficulties	General level of confidence in operator	Operator (not) prone to commit grave errors	Operator prepared for difficulties
Chemistry	AN	**c**	0	–	0	0	0	0		0	0	–	0	0	+
	BO	**c**	0	0	+	0	0	0		–	+	0	0	+	+
	CP		0	+	+	0	0	0		+	+	**+ +**	+	+	+
	DQ		–	–	–	0	–	–		–	–	–	–	–	–
	ER	**c**	0	0	0	0	–	0	**c**	0	0	–	+	+	+
Mechanical Engineering	FS		–	0	–	0	0	0	**c**	0	0	–	+	+	+
	GT	**c**	0	+	0	–	–	–		+	+	–	–	0	0
	HU		–	–	–	–	–	–		0	–	0	–	–	–
	IV		0	–	0	–	–	0		0	+	+	+	+	+
Physics	JW	**c**	0	0	–	0	0	+		0	0	0	0	0	0
	KX		– –	–	–	– –	– –	–		+	+	+	+	+	**+ +**
	LY		+	0	+	0	0	+		0	0	+	0	+	+
	MZ		–	–	–	–	0	0		0	0	+	0	0	0

We consider the additional information from the debriefing interviews as necessary and complementary to the indicators. It was our intention to use the questionnaire also as a platform for discussion [58] because, in our opinion, the sole use of a multiple-choice questionnaire would have been too limiting to explore these complex attitudes.

A.2 Subject profiles

Here are the profiles of our participants described in terms of background in physics and experimental work, self-assessed expertise with computers and positive attitudes toward them, *a priori* attitudes toward simulation as an educational medium, and prior experience with simulation and multimedia applications bearing similarities to the VPLab. It would be very useful to read a subject's profile just before reading the account of his individual session exposed in Appendix C.

Some of the information in these profiles has already been presented in the preceding section: it was obtained mainly through a telephone interview (which was conducted by following a closed-ended questionnaire) and also by having subjects fill out a written closed-ended questionnaire before the session. The rest of the information in the following profiles was obtained through a structured interview conducted just before the subject interacted with the VPLab.

A.2.1 Subjects AN, BO, CP, DQ, ER: chemistry students

Subjects AN through ER were enrolled in the same bachelor's degree program, specialized in chemistry (chemistry courses make up all of the curriculum, with few exceptions). At the time of the sessions, all of these subjects were taking an experimental physics course for chemistry students. [59] All except one (AN) were taking or had taken two university-level theoretical physics courses for chemistry students. One of these theoretical courses dealt solely with content in classical mechanics and wave physics . Hereafter, we shall refer to these subjects as "chemistry subjects". [60]

Subject AN

At the time of his session, subject AN had resided in Quebec for the past 4 years. He [61] is originally from Zaire, where he was schooled up to high school level (lab equipment was

[58] Note that it was necessary to wait until the end of the debriefing period to engage in a discussion regarding attitudes toward simulation. This was done to avoid 'contamination' of the attitudes towards the VPLab itself.
[59] This experimental physics course for chemistry students did not feature any classical mechanics experiments (the VPLab's air-table experiment applies theory in this field of physics).
[60] Similarly, subjects enrolled in engineering and physics programs shall be referred to as "engineering subjects" and "physics subjects"
[61] Masculine pronouns and adjectives are used throughout for both male and female subjects. As a precaution, we have chosen to conceal gender in order to inhibit unwarranted associations between certain attitudes and gender.

scarce in Zaire.) AN had the weakest physics background of the "chemistry subjects" (he had not taken any university-level theoretical physics courses).

AN seemed aware of statistical variation in experimental outcomes [62] but didn't like the fact that he usually couldn't get experimental results exactly identical to those contained in text books and reference tables (for this, he blamed the quality of his material and the fact that he could only do the experiment once). He also seemed to think that manual dexterity was an important ability to be developed during an experimental physics course.

AN is the only subject who gave relatively low ratings on all three scales pertaining to positive attitudes toward computers (see table A.1). He also gave relatively low *computer expertise* self-ratings in regards to all of the common applications enumerated in the preliminary questionnaire (see table A.2), and these ratings might be correlated with his report of less frequent use of advanced functions in window-based operating systems (see table A.3).

AN is the only subject with **no prior experience whatsoever of simulation use** (see table A.4). He is also one of four subjects who reported the *least* frequent overall use of four multi-media applications bearing similarities to the VPLab (see table A.5). This could predispose AN to perceiving the VPLab as being quite strange or novel. It is worth mentioning, however, that this subject also claimed to have watched many scientific documentaries on television and to have benefited very much from them ; he thus supposed that content presented by way of multimedia may sometimes be more beneficial than content transmitted through conventional means (classrooms, textbooks, etc.).

A priori **attitude toward simulation as an educational medium**

The indicators for *a priori* attitudes toward simulation in table A.6 do not clearly show that AN had unfavorable attitudes. In regards to use of simulation for training (see right half of table A.6), we believe in the accuracy of the indicators which do not seem to reveal an unfavorable attitude. However, comments made by AN as he was being debriefed on how he answered the pre-interaction questionnaire seem to indicate an unfavorable attitude toward simulation when used to illustrate physics concepts (see left half of table A.6). [63]

Subject BO

This subject considered lab experiments to be somewhat akin to extra-curricular activities, given the fact that students are called upon to learn by handling apparatus (in contrast to the work required by lectures).

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[62] By 'statistical variation of experimental outcomes', we mean that when experiments are repeated many times, different results can be obtained from trial to trial (following a probabilistic function) and that reference values for known physical quantities are derived by repeating an experiment and by applying statistical methods in processing results of multiple trials.

[63] AN had this to say about answering the questionnaire:

> *I was a bit confused. It wasn't very clear in my mind that it was a computer simulation. I thought of it more as if it was video. So… I could lower [my rating] a bit.* [citation 25]

We interpret the last sentence to mean that given the chance, AN would lower his approval ratings of simulation (in comparison to video) in the context of learning physics concepts. Later, when comparing video and simulations, he also said that "when you see what really happened, it's a video" [citation 26] . Based on this, we think that AN attributed less of a reality status to simulation than he did to video.

In college (CEGEP general program[64]), BO had had prior experience with the use of an air-table in an experimental context. It is important to note that the functionality of the rig he used to collect data during this experiment, if more rudimentary, was somewhat analogous to the VPLab's functionality. It made use of rapid photography and a phosphorescent marker to record successive positions of the disc. Analysis was then performed by developing the film and projecting the pictures on a screen using an overhead projector. Also noteworthy is the fact that BO had never used a real camcorder. This could have some impact on his judgments concerning the VPLab's main metaphor.

This subject had made prior use of social science simulations and he had also played with very 'realistic' video games.

A priori attitude toward simulation as an educational medium

Indicators for *a priori* attitudes toward simulation do not allow us to conclude that BO had an unfavorable attitude. However, based on answers given during the debriefing interview, we could attribute him a slightly more unfavorable attitude toward simulation when used to illustrate physics concepts, than is indicated by table A.6.

Based on the debriefing interview, we believe that this subject's indicators for attitude toward simulation when used for skill training are accurate. They show that he does not have unfavorable attitudes in this context (see right half of table A.6).

Peer influence

Analysis of data from the session with subject BO adds a very important dimension to our findings: in the course of our interview with BO, it came to our attention that at least one previous participant – subject CP – had spoken to subject BO about his experience prior to BO's session: [65]

> ***BO**: Well, one classmate told me that if [the VPLab] was available, he would get it. This friend who spoke to me doesn't like physics. And he told me: "It [the VPLab] helped me to understand things that I hadn't understood in class". [On the sole basis of] having done the test here, he said that [the VPLab] looked like it was really well designed and that, although he isn't a physics student, this would be the kind of software he would buy. But no, they [i.e. other subjects] did not say anything of… I was not aware of…*
>
> ***Interviewer**: I'm just curious… Did they mention any of the questions [that you would be asked here today] ?*
>
> ***BO**: No.* [citation 27]

One might be tempted to disqualify BO's data on this basis. On the contrary, we make it a theoretical stand to stipulate that, in reality, users are not confined to a closed box and can rather be influenced by third parties – in effect, that a product's credibility (verisimilitude

[64] In Québec, CEGEPs (an acronym which stands for the French designation "Collège d'enseignement général et professionnel") offer two-year general programs, leading to university studies, and three-year technological programs which usually lead to the job market. In comparison to the US educational system, the general CEGEP program is roughly equivalent to the last year of high school and the freshman year of college. (In Quebec, a university undergraduate degree in chemistry or physics requires students to acquire 90 credits and usually lasts three years. A university degree in engineering requires students to obtain more credits and usually lasts longer – from three and a half to four years, depending on the university.)

[65] Subject CP, whom BO had spoken to prior to his session, was rather favorable to simulation as an educational medium (see table A.6).

being a special kind of credibility) may usually be somewhat grounded in social interaction or affected by information acquired through other media. Hence, it is acceptable to include this kind of data in our study.

Subject CP

This subject felt that learning the scientific method was important in an experimental physics course. Let's note that CP disliked physics in general and also disliked the physics experiments that he was performing at his university ; he felt he didn't understand what he was being asked to do.

In the past, CP had usually obtained experimental results that came close to theoretical predictions and he thought that students would only rarely obtain results that were completely off. He seemed to feel that it was the experimenter's fault when this happened (which could indicate that he was not very aware that malfunctions, anomalies and inadequacies in an experimental set-up might affect the outcomes of an experiment).

This subject had prior experience with an air-table in an experimental context and also with a tracing system that worked by sending electrical discharges on carbon paper.

In regards to positive attitudes toward computers (see table A.1), CP is one of 5 subjects who gave the maximum rating on all three scales used in the preliminary questionnaire (*perceived ease of use*, *perceived pleasantness of use*, *perceived usefulness*). He is also one of 5 subjects who rated their own computer expertise relatively high in regards to most of the common applications enumerated in the preliminary questionnaire.

Although CP had made no prior use of simulations in an educational context, he did report playing realistic video games and using two other types of multi-media applications bearing similarities to the VPLab (see table A.4 and 4.5).

A priori **attitude toward simulation as an educational medium**

It is clear, considering the indicators in table A.6, that CP had very favorable attitudes toward simulation as an educational medium; this seems to be confirmed by the comments made during the debriefing period. [66]

Subject DQ

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[66] Here's a sample that illustrates CP's favorable attitude very well:

> ***CP:*** *[...] everything can be manipulated… Well, notice that today, if I show you a video clip, it can be created from A to Z on a computer and it is fictive. […]*
>
> ***Interviewer:*** *For you, the difference between the two [simulation and video], is it still…*
>
> ***CP:*** *No, as far as I'm concerned, there is no difference [between] a video and a computer because both can be manipulated. If you've seen the movie Star Wars [Episode One], there is [only] one scene that was truly filmed ; but for the rest of the movie, you say: "My God, is it real ? It seems real !" And it was all done with computers but you'll watch it on your TV screen.* [citation 28]

Based on his prior experience, subject DQ had found conducting laboratory experiments enjoyable and felt that "touching" apparatus , in contrast to just reading or listening to a teacher, could help him better understand phenomena. He considered precision in one's work an important skill to acquire in an experimental physics course. He believed it important to try to closely follow experimental protocol and to strive for the best possible results. He felt it was discouraging to work with some of his university's lab equipment because it was old and lacked precision, and thus degraded experimental outcomes.

This subject had prior experience with an air-table in an experimental context and also with a tracing system that worked by sending electrical discharges on carbon paper.

In regards to self-assessed attitudes toward computers, it is noteworthy that DQ's self-rating for *perceived ease of use* was lower than his self-ratings for perceived *pleasantness of use* and *perceived usefulness.* This might mean that he possesses less confidence in his own abilities to operate successfully with computers.

DQ had little prior experience with simulation, except for playing SimCity. [67] He is also one of four subjects who reported the *least* frequent overall use of four multi-media applications bearing similarities to the VPLab (see table A.5). This could predispose DQ to perceiving the VPLab as being quite strange or novel.

A priori **attitude toward simulation as an educational medium**

It is clear, considering the indicator values in table A.6, that DQ had an unfavorable *a priori* attitude towards simulation as an educational medium. Comments made during the debriefing session seem to confirm this.

Difficulty with use of the interface

It should be noted that, of all subjects, DQ seemed to have the most difficulty in using the VPLab's interface (with the possible exception of GT) . This may have caused him to be more negative in his judgments toward the VPLab.

Differences in mental models of a phenomenon (the disc's deceleration)

After DQ had launched the disc on the air-table while the merry-go-round was turning, the interviewer asked him to explain why the disc was slowing down. We expected him to say, like most subjects, that the deceleration was caused by the simulation of non-zero air friction working against the disc's motion. Instead, he attributed the disc's deceleration to the merry-go-round's continuous rotation. (Observe that DQ still put forward an explanation and did not just say: 'I don't understand, this can't be happening.' [68]) We take

[67] SimCity, a popular video game, is basically a simulation of a city and its problems. The player acts as mayor. This game has been praised for its realism and has sometimes even been used in educational contexts.
[68] Of course, if he truly did not understand what was happening, he may have felt obliged to put forward an explanation anyway in the context of the session, i.e. because he was being asked by an interviewer in a

this as evidence that he had a different mental model of the simulated phenomenon. As is the case of actual experiments, a cue can be used quite differently by subjects depending on their mental model of a phenomenon.

Subject ER

Concerning prior lab work, ER hadn't enjoyed the classical mechanics experiments he had performed in college (CEGEP general program) because he hadn't possessed sufficient knowledge of the theory and of the instruments to understand the experiments.

However, ER did say that experiments were important in a physics course because they allowed students to verify the validity of a theory by observing reality and by manipulating objects.[69]

This subject had prior experience in working with an actual air-table. That table, however, was different from the table represented by the simulation: instead of pumping air through holes in the table's sides, the air cushion was created by pumping air down through a hole in a disc made of *metal* (a layer of air was thus created between it and the table). In such a case, the disc's behavior can be somewhat different. ER also had prior experience with a tracing system that worked by sending electrical discharges on carbon paper.

ER gave relatively low *computer expertise* self-ratings in regards to most of the common applications enumerated in the preliminary questionnaire (see table A.2), and these ratings might be correlated with his report of less frequent use of advanced functions in window-based operating systems (see table A.3).

This subject had made prior use of a small educational program containing physics simulations and he had also played SimCity. He is also one of four subjects who reported the *least* frequent overall use of four multi-media applications bearing similarities to the VPLab (see table A.5) ; this could predispose him to perceiving the VPLab as being quite strange or novel.

A priori **attitude toward simulation as an educational medium**

Indicators in table A.6 do not establish that ER had an unfavorable attitude towards use of simulation in the context of illustrating a *mechanics* concept. However, comments made by ER during the debriefing interview seem to establish that he had such an unfavorable attitude:

> ***ER****: Chances are better that things really happened if they were filmed then if they are depicted with images.*
>
> ***Interviewer****: Would the video clip and the computer simulation be about equal for you ?*
>
> ***ER****: No… I would prioritize video.*
>
> ***Interviewer****: On a scale of 1 to 5 ?*
>
> ***ER****: Video would be higher than simulation.* [citation 29]

---

position of authority (though only a few years older than the subject) to explain a simulated scientific phenomenon.

[69] This might play against the VPLab, should the subject feel that a simulation is not an appropriate means of verifying a theory's validity.

Conversely, in regards to illustrating a *relativity* concept, ER's comments would suggest that he had a more favorable attitude toward simulation in this context than what indicators would lead us to believe.[70]

As for his attitude toward simulation in the context of training for a low risk/mechanical operation, this subject may have had a slightly more unfavorable attitude than is indicated in the right half of table A.6. Finally, ER's comments confirm a favorable attitude toward use of simulation in the context of training for surveillance and diagnostic of a nuclear reactor. His arguments were that this task is computer-based and that physical handling of the devices is less relevant in this case.

Lack of guidance

We have mentioned that ER was not keen on doing experiments without proper guidance. This is important because the very first comment made by this subject during the debriefing interview was to express that the VPLab was difficult to use without instructions as to how and without help on its features. He also felt that he had experienced difficulties during the session because he lacked information, usually dispensed before a lab session, concerning the purpose of experimental activities and the types of measurements that should be performed. This lack of information, which was inherent to our method, seems to have had a negative effect on ER's attitudes.[71] For instance, he felt distracted "from the physical phenomenon by the gadgets [instruments]" and we think that his difficulties with the virtual instruments, due to lack of experience and proper guidance, may have been partly responsible for this feeling of distraction.

A.2.2 Subjects FS, GT, HU, IV: mechanical engineering students

Subjects FS through IV were enrolled in the same mechanical engineering bachelor's program. Hereafter, we will refer to these subjects as 'engineering subjects'. These subjects were attending a university different from the one both chemistry and physics subjects were attending. This university is special as it requires students to have acquired a three-year *technological* degree at college level (CEGEP)[72] prior to admission. At the time of the sessions, all engineering subjects had taken or were attending at least one mechanical

[70] The subject stated that his answers to the pre-interaction questionnaire did not reflect what he really thought.

[71] The VPLab would normally be used in a more purposeful way and with resources like on-line help, a coherent and goal-driven pedagogical scenario (protocol), tutor assistance, peer collaboration, etc. None of these were available to subjects because our interest was to identify verisimilitude cues that would emerge primarily from within the software environment itself and also because we did not have the resources needed to implement a method according to which subjects would conduct full-fledged lab experiments, analyze results and hand in lab reports.

[72] In Québec, CEGEPs (an acronym which stands for the French name "Collège d'enseignement général et professionnel") offer two-year general programs leading to university studies, and three-year technological programs which usually lead to the job market. Students enter the technological programs following their fifth high school year. Note that three of the four engineering subjects (the exception being subject GT) had also previously studied within the *general* CEGEP science program, for various lengths of time.

engineering course which required them to do classical mechanics experiments (more precisely, statics experiments [73]).

Three of these four engineering subjects (with GT as the notable exception) gave the maximum rating on all three scales pertaining to positive attitudes towards computers. These same three engineering subjects also rated their own computer expertise relatively high in regards to most of the common applications enumerated in the preliminary questionnaire.

Most importantly, and contrary to other subjects, all of the engineering subjects had made use of computer-assisted design (CAD) software packages (these software tools afford much precision when designing system components). Not only did they design mechanical components with this software, but they also **simulated** them, in order to inspect aspects of their behavior. Consequently, these subjects had probably made more extensive prior use of simulations than most of the other subjects.

Subject FS

FS believed that experimental work was essential to any physics course because it allowed one to prove the validity of theoretical propositions which could otherwise always be subject to doubt. FS claimed that he enjoyed hands-on experimental work. Even before seeing the VPLab, the subject spontaneously said: "*I have to touch things, so simulations will often work so-so [for me]*" [citation 30]. FS also said that he enjoyed performing challenging experimental manipulations requiring dexterity. He thought that acquiring precision in one's work and applying oneself when performing experimental manipulations should be important objectives of an experimental physics course.

In contrast to some of the other engineering subjects (and chemistry subjects), FS seemed to have more technical knowledge, but also a better grasp of theoretical knowledge concerning the subject matter which applied to the simulated experiment chosen for this study (i.e., rotating frames of reference).

In regards to positive attitudes toward computers, FS is one of 5 subjects who gave the maximum rating on all three scales used in the preliminary questionnaire (*perceived ease of use*, *perceived pleasantness of use*, *perceived usefulness*). He is also one of 5 subjects who rated their own computer expertise relatively high in regards to most of the common applications enumerated in the preliminary questionnaire.

FS reported '*more'* frequent use of three types of multimedia applications bearing similarities to the VPLab, including realistic video games (see table A.5).

A priori attitude toward simulation as an educational medium

FS did not have an unfavorable *a priori* attitude toward simulation when used to illustrate a concept in the theory of special relativity. Table A.6 indicates that his attitude toward

[73] Statics is the subdivision of classical mechanics that is concerned with the forces that act on bodies at rest under equilibrium conditions (Encyclopedia Britannica, 2001). The VPLab's experiment did not deal with statics but rather with dynamics, which is another subdivision of physics concerned with forces acting on bodies in motion.

simulation when used to illustrate a classical mechanics concept was slightly unfavorable and this is confirmed by comments made during the debriefing interview.

It is not clear, considering information in table A.6, whether this subject had an unfavorable attitude towards simulation when used to train an operator for a low risk/mechanical operation. Comments made during the debriefing interview establish that FS had a rather unfavorable attitude toward simulation in such a case. However, this data also confirms that his attitude was favorable toward simulation when used to train for a computer-based task.[74]

Type of simulation expected

We wish to note that FS was rather expecting to try software comprised of **non-visual** simulation that would mainly display numbers. When he first saw the Manipulation workspace, FS seemed satisfied because the application actually depicted objects:

> *Often enough, you'll have home-made software and the person who uses it [first], knows what it's for. But for people who are learning, it's not fun to only have a textual display and enter data. To perform experimental manipulations, you have to try to make it as visual as possible because most people are visually oriented […] At least, you see here [with the VPLab] that it simulates something: there's a chronometer…* [citation 32]

Subject GT

GT had previously worked in the field of aeronautics as a parts inspector. He claimed that *precision* in one's work was crucial in this field.

He felt that learning how to handle apparatus adequately while using a rigorous method was essential in an experimental physics course. When asked what he liked about performing experiments, GT answered that he enjoyed obtaining conclusive results, given that an experiment's main goal is precisely to prove something (and illustrate the laws of physics).[75] GT liked to work with a well defined experimental protocol which allowed him to *obtain results with a small error margin*. In his opinion, when students obtain large margins of error, blame should be cast either on the experimenter himself or on the experimental protocol. Of all the subjects, GT has the weakest physics profile (fewest physics courses taken.)

In regards to positive attitudes toward computers, GT is the subject whose ratings vary the most from one scale to the other (see table A.1): his rating for *pleasantness of use* was lower than the one for *ease of use*, which was in turn lower than his rating for *usefulness*.

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[74] Concerning simulation when used to train operators for diverse tasks, ER said :

> *A computer simulation of something that is itself normally controlled through a computer [e.g.: a nuclear reactor] will work well. However, if you simulate something like a jib-crane, the [operator] gets on the crane and if manual operations are required, then he will have difficulties because [..] this requires "manual feel" and he'll never know that. And you have a phenomenon [associated with] the power [of the machinery] – it's not the same.* [citation 31]

[75] This subject also mentioned that getting mathematical proof of theoretical propositions was necessary for engineers.

GT reported '*more*' frequent use of three types of multimedia applications bearing similarities to the VPLab, including video games [76] (see tables A.4 and A.5). Like all the engineering subjects, he had conceived simulations of mechanical components (with CAD packages) which, he thought, were "very, very realistic".

***A priori* attitude toward simulation as an educational medium**

Table A.6 indicates that subject GT had an unfavorable attitude toward simulation when used to illustrate a relativity concept but not when used to illustrate a classical mechanics concept. This was confirmed by comments made during the debriefing interview. However, the only reason given by GT to explain why he favored simulation in the case of the classical mechanics concept, was that he was already familiar with the 'solution' to the specific 'problem' involved in the questionnaire (see Appendix B). In our opinion, this indicates that GT could doubt simulation in any case where he would not be familiar with the subject matter.

Indicators in table A.6 do not allow us to conclude that GT had an unfavorable attitude toward simulation when used for training. Comments made by GT during the debriefing interview indicate that he did not have an unfavorable attitude in this context (or only very slightly so, in the case of the high risk/computer-based task).

Subject HU

HU said that performing experiments was important to him because he considered himself a rather practical person and because experiments allowed him to better assimilate subject matter. In his opinion, practical skills, greater understanding of theory and rationality were among the abilities or qualities that an experimental physics course could help promote.

In regards to positive attitudes toward computers, HU is one of 5 subjects who gave the maximum rating on all three scales used in the preliminary questionnaire (*perceived ease of use*, *perceived pleasantness of use*, *perceived usefulness*). He is also one of 5 subjects who rated their own computer expertise relatively high in regards to most of the common applications enumerated in the preliminary questionnaire.

HU had prior experience in working with an actual air-table and with a tracing system that worked by sending electrical discharges on carbon paper.

Of prime importance is the fact that HU had seen a documentary in which the motion of an object had been analyzed "using a camera" (and, in all probability, using video processing tools).

***A priori* attitude toward simulation as an educational medium**

From table A.6, it is clear that HU had an unfavorable attitude towards use of simulation in all contexts involved in the preliminary questionnaire, except possibly, in the context of

[76] During the debriefing interview, GT claimed that video games "still had a long ways to go" in terms of realism.

training for a low risk/mechanical operation (scrapyard task). Comments made by the subject during debriefing indicate that the indicators in table A.6 are correct. In addition, note that HU deemed use of a simulation acceptable in the case of the scrapyard task only because this task seemed very simple to him.

Subject IV

Subject IV felt that he had had more success in physics courses which required him to do experiments and handle apparatus, than in other physics courses. He said that hands-on activities allowed him to better assimilate subject matter. For this subject, an important part of an experimental physics course was coming into contact with instruments and learning how to handle them.

In regards to positive attitudes toward computers, IV is one of 5 subjects who gave the maximum rating on all three scales used in the preliminary questionnaire (*perceived ease of use*, *perceived pleasantness of use*, *perceived usefulness*). He is also one of 5 subjects who rated their own computer expertise relatively high in regards to most of the common applications enumerated in the preliminary questionnaire.

IV's past experience with simulation is of foremost importance: he had had the opportunity of trying out two different industrial flight simulators (made by a firm which had employed him).

A priori attitude toward simulation as an educational medium

Indicators in table A.6 indicate an unfavorable attitude towards simulation when used to illustrate a concept related to the theory of relativity, but still leave doubt as to subject IV's attitude in the case of the classical mechanics concept. The debriefing interview data indicate unfavorable *a priori* attitudes in both cases and lead us to believe that the subject may have had a slightly more favorable attitude in the case of the classical mechanics concept than in the case of the relativity concept, but only because the latter appeared to be more counter-intuitive.

The debriefing interview data confirm what the indicators in the right half of table A.6 show, which is that subject IV had a rather favorable attitude towards use of simulation for skill training. This is linked to his prior contacts with industrial flight simulators and to contact with users (pilots) who praised their fidelity.[77]

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[77] Here are some of IV's comments about simulation when used from training:

> ***IV****: I tried the RJ and the CF18 [simulators], it was fun.*
>
> ***Interviewer****: Did you have the impression that it really represented…*
>
> ***IV:*** *Yes, that's why, when I got to that question, earlier in the questionnaire, of someone who tested a jib-crane on a simulation and " is he ready to operate the [real] jib-crane ?" I answered "yes", because I know that a pilot with the slightest prior experience, if you [first] stick him in a simulator, he can then go on to pilot the plane with no problems whatsoever. He won't even realize that he's not in his simulator anymore, and that he's in the plane instead: there's no difference. If the simulation is well designed, then we're happy. It's like the nuclear power-plant [question]: no matter if it's a nuclear power-plant which can cause a lot of damage, as long as the interface [of the simulation] is the same, there is no difference. So that's why I trust simulation.* [citation 33]

A.2.3 Subjects JW, KX, LY, MZ: physics students

Subjects *JW* through *MZ* were all enrolled in a physics program, although the curriculum of their respective programs varied somewhat. Hereafter, we will refer to these subjects as 'physics subjects'. Three of them (KX, LY, MZ) were attending the same university. The physics subjects should be considered as having the strongest backgrounds in physics and the most knowledge of subject matter pertaining to the VPLab's simulated air-table experiment.

At the time of the sessions, all physics subjects had taken or were attending at least one experimental physics course which featured some classical mechanics experiments among experiments in various fields of physics. It should also be noted that at the time of the session, at least three of the physics subjects (KX, LY, MZ) had conducted an experiment at their university, using software to acquire data, in real-time, from apparatus (and to draw graphs displaying this data).

Subject JW

Subject JW was from Puerto Rico and was much less fluent in French than in English (only French was used in the VPLab and the session was mostly conducted in French [78]). At the time of the session, this subject was attending a different university than the three other physics subjects. The total number of university-level physics courses he had attended (at the time of the session and during prior semesters) was 13 – which is more than any other subject.

JW claimed that he often did not sufficiently understand what he was doing when he performed lab experiments, and he thought that this might explain why he did not generally enjoy doing so. Although he did not enjoy lab work, JW acknowledged that hands-on work (manipulating objects with one's hands) was necessary because it allowed him to have a better grasp of abstract concepts (e.g., conservation of momentum).

This subject reported having little prior experience with use of simulation. JW is also one of four subjects who reported the *least* frequent overall use of four multi-media applications bearing similarities to the VPLab (see table A.5). This could predispose him to perceiving the VPLab as being quite strange or novel.

A priori attitude toward simulation as an educational medium

[78] The multimedia explanations of the simulation were in French as well: to make up for JW's linguistic disadvantage, the interviewer thought it appropriate to explain the Manipulation workspace simulation after the subject had explored it.

Indicators in table A.6 do not allow us to conclude that JW had an unfavorable attitude toward the use of simulation to illustrate physics concepts. However, comments made by JW during the debriefing interview indicate that he had such an unfavorable attitude.

The interviewer did not have the opportunity to verify JW's neutrality in the context of skill training, as is indicated in the right half of table A.6.

Subject KX

Subject KX was enrolled in a mixed *physics/computer science* bachelor's program and had completed 7 university-level physics courses as well as courses in computer science. This subject stated that he did not generally enjoy performing lab experiments and was rather theoretically oriented. The reason he did not enjoy lab work was that he was being asked, in an experimental physics class at his university, to perform experiments without having a sufficient grasp of the corresponding theory: he thus had the impression of not fully understanding what he was doing. When he did have a good grasp of specific theoretical knowledge, one of the things he enjoyed about lab experiments was the opportunity to "validate" this knowledge.

In his opinion, statistical analysis of results was an essential skill to acquire in the course of an experimental physics class – ironically, KX also claimed that he did not enjoy performing statistical analysis and writing reports. Dealing with uncertainty was also seen by KX as an essential process.

Despite his background in computer science, this subject reported having no prior contact with computer simulation, other than playing realistic video games. [79]

A priori **attitude toward simulation as an educational medium**

Indicators in table A.6 show that KX was the subject who had the most unfavorable attitude toward simulation when used to illustrate physics concepts. This attitude was confirmed by comments made during the debriefing interview. It was expressed at least in part through arguments which involved the very construction of a computer model.[80] As such, the case of subject KX compared to other physics subjects is very informative:

> *A simulation does not help to convince you, in the end. It shows you– "Look, I've programmed this thing and I can obtain the right result". However, with [the video clip], you can't help but believe it […] it hasn't been rigged. It's easier to believe that the simulation has been rigged than [to believe that the video clip has been rigged or has been tampered with]. In addition, a simulation is based on equations, so that if your equations are flawed, your simulation will give you the outcome that you expect – [this is] in contrast to a video clip which is not based on equations but rather on reality, as such…* [citation 34]

Interestingly, KX had a very favorable attitude towards the use of simulation for skill training, as is indicated in table A.6 and confirmed by the debriefing data. It is noteworthy that the possibility of a faulty model, which was KX's main grievance against simulation

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[79] Moreover, KX's computer science background does not necessarily entail that we should consider him an 'expert user' in regards to the VPLab (see table A.3) – programming expertise does not necessarily intersect with expertise needed to use the VPLab's 'direct manipulation' interface.

[80] His argumentation also rested on the assumption that a video clip was always a pristine representation/recording of reality.

(as shown by the preceding excerpt) was either completely overlooked or was not a factor in the case of skill training.

Subject LY

Distinctively, this subject believed that honesty and ethically correct behavior was something that students should acquire when doing an experimental physics course: learning to not falsify data and trying to explain why an experiment had been inconclusive were important to LY. Another important element which LY thought that students should acquire was "research acumen" [*l'esprit de recherche*] which he defined as being alert and proactive (during an experiment) by trying to anticipate the behavior of phenomena, as opposed to having a passive attitude and just waiting around for results.

In LY's opinion, the main goals of experimentation in a physics course were verifying theory and learning how to use measuring instruments. Interestingly, LY also felt that experimental error "was part of the game," and that "students didn't learn anything from perfect labs." The purpose of a lab experiment, he said, is also to learn about errors caused by instruments: "You learn about theory and at the same time, you learn that instruments are not perfect." [citation 35]

LY considered that experiments had to have visual components ; in his opinion, a learning activity which made use of a model implemented through MathLab software or MAPLE software could be "like an experiment" if students could view graphs (or other visual representations).

Before enrolling in a physics program, this subject had studied during two years in a software engineering program. In regards to positive attitudes toward computers, LY is one of 5 subjects who gave the maximum rating on all three scales used in the preliminary questionnaire (*perceived ease of use*, *perceived pleasantness of use*, *perceived usefulness*). He is also one of 5 subjects who rated their own computer expertise relatively high in regards to most of the common applications enumerated in the preliminary questionnaire.

In college, this subject had conducted an experiment with an actual air-table which could be rotated about its center (in the VPLab's simulation, the merry-go-round is used to rotate the table and people can view motion on the table from inside the rotating frame of reference). Instead of a disc, he had used marbles as projectiles in this experiment. He had also used a carbon paper tracing system.

It is crucial that LY had much prior experience with simulations and MAPLE software in an experimental context (as well as with SimCity video and other "very realistic" video games). In particular, LY had taken a college-level physics course which was designed to fully integrate MAPLE software in all aspects of class-room activities, both theoretical and experimental.

A priori attitude toward simulation as an educational medium

Relying on indicators in table A.1, we may say that subject LY was rather favorable to simulation. The debriefing data confirm this and offer excellent examples of expression of such attitudes:

> ***LY**: […] the video sequence can do anything, really – it does whatever you tell it to do, whereas the simulation behaves in accordance to mathematical calculations. In the case of the video sequence, you'll say: "Maybe, it was just drawn that way," whereas with the program, if in fact you are shown with disclosure what is really happening using vectors and such, it's more credible.*
>
> ***Interviewer**: OK, so a video sequence can be…*
>
> ***LY**: It can be anything. Take movies: you have special effects, etc. Well, I may be pushing it a little… You do tell yourself that your school isn't working against you, but that notwithstanding… Normally, I would have more trust in simulation – it proves more. Video shows no proof. It's like television. If you watch television, you are passive – with simulation, you can interact […] That's what we used to do in physics with MAPLE [software]: we had a model and we could change the data […] and the model would change in accordance. Then we verified this manually by calculations on the blackboard and saw that things were accurate.* [citation 36]

Note that one of the reasons LY did not favor video over simulation is that he did not automatically equate a video clip with a 'historical representation of reality'.[81] The subject also felt that simulation was more interactive and was a better support for mathematical explanations than video. Ultimately, his prior use of simulation (through MAPLE software), which had apparently been very beneficial to him, probably contributed heavily to LY's favorable attitude towards this medium.

Subject MZ

Subject MZ was enrolled in a physics/mathematics mixed bachelor's program and had attended 8 university-level physics courses (some of which were courses attended at the time of the session and others, courses completed in the prior semester). He seemed to have a better grasp of rotational frames of reference (a concept crucial to the VPLab's air-table experiment) than most other subjects.

MZ had prior experience with an air-table in an experimental context and with a tracing system that worked by sending electrical discharges on carbon paper.

The subject felt that it was necessary for students taking an experimental physics course to learn how to handle widely used instruments (e.g., oscilloscopes, multimeters) and he felt that students should also get an idea of widespread phenomena (e.g., interference, diffraction, a simple electric circuit).

Of all subjects, only MZ seemed to be very interested in aspects dealing with experimental design. Although he did not often get the chance to do so, he really enjoyed applying the experimental method (defining a problem, trying to find a solution, thinking about the experimental set-up, etc.). He also said that he enjoyed analyzing experimental data. These are distinctive traits that matter very much, with respect to our study.

MZ reported having little prior experience with use of simulation: he had made scarce use of software that simulated stellar motion.

[81] Tellingly, however, the subject did say that a "real video" with "real people" (by which he undoubtedly meant 'a historical representation of reality' – something that was truly filmed and not tampered with) had a special status.

A priori attitude toward simulation as an educational medium

Indicators in table A.6 show that MZ had an unfavorable attitude toward simulation when used to illustrate physics concepts. This was confirmed by comments made during the debriefing interview:

> *You can't help but be perfectly convinced when the experiment is conducted in front of your eyes. And viewing a video sequence is almost equivalent to having the experiment conducted in front of your eyes – you can't say a thing… Whereas, in the case of a computer, effects that infirm [theory] are just as programmable [as those which confirm theory].* [citation 37]

We must add, though, that MZ's trust in video data was not absolute and that he did not attribute any scientific value to proof solely presented through video :

> ***Interviewer****: More people would be convinced by the video clip [than by the simulation] ?*
>
> ***MZ****: […] Yes. However, that may not be a positive thing. Perhaps it's an aspect of media in our time: "This really happened: look we filmed it !"*
>
> *– Ah yes, now I believe it.*
>
> *But that doesn't mean that it would be more credible objectively. I think people would be more convinced but that doesn't mean that it would be more credible…*
>
> ***Interviewer****: From a scientific point a view ?*
>
> ***MZ****: Yes, that's it: from a scientific point of view, [video] has no value.* [citation 38]

The interviewer did not have the opportunity to verify MZ's neutrality in the context of skill training, as is indicated in the right half of table A.6.

APPENDIX B: QUESTIONNAIRE AND COMPUTED INDICATOR VALUES FOR *A PRIORI* ATTITUDES TOWARD SIMULATION AS AN EDUCATIONAL MEDIUM

B.1 Questionnaire for *a priori* attitudes toward simulation (english translation)

Here is the English translation of the questions that subjects were asked in order to assess their *a priori* attitudes toward simulations as educational media (the original French version can be found in section B.3). These questions (numbered M5 to M12) were part of a larger questionnaire which subjects answered prior to interacting with the VPLab. Questions M5 to M8 involve computer simulation ; questions M9 to M12 are almost identical to these, but involve other media instead of simulation. These two sections were given to subjects separately. Near-identical pairs can be formed with questions M5 and M10 ; M6 and M9 ; M7 and M11 ; M8 and M12. Answers within these pairs were compared in order to compute the indicator values contained in tables B.1 and B.2, which can be found in section B.2, following the questions.

- - - - - - - - - -

« It would be useful to have your opinion regarding the various instructional methods used in the following cases. *(Beware, the objective is not to have you solve the physics problems that are described in some of these situations ; in fact, the solutions to the problems are already given. Do not hesitate to ask questions in case you have a problem – that's what I'm here for!)*

M5. You belong to a group of students taking a «Mechanics 101» physics course (dealing with dynamics). At the beginning of class, the teacher mentions a fact which seems counter-intuitive to the students. Many students are skeptical. The teacher thus decides to illustrate the problem with a *computer simulation*.

The *computer simulation* shows a wooden cube floating (due to the absence of gravity) in the cockpit of the space shuttle, which is orbiting the earth. A tennis ball is twice launched on the wooden block, which has a Velcro covering on one of its faces.

In the first case, the tennis ball is launched on the face of the cube covered with Velcro, and the ball sticks to the cube after the collision.

In the second case, the ball is launched on a cube face **not** covered in Velcro, and thus the ball **bounces off** the cube after the collision. (A special device allows launching the ball at the same speed in both cases.)

The speed of the cube after collision is compared between the two cases. The result: The speed of the wooden cube is greater in the case where the ball **bounces off** the face of the cube not covered in Velcro. The *computer simulation* clearly shows this result.

A) Approximately estimate the percentage of skeptical students in the class which, in your opinion, would be completely convinced by this simulation.

☐ 0% ☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ 60% ☐ 70% ☐ 80% ☐ 90% ☐ 100%

Circle the number which corresponds to your opinion regarding the following propositions:

B) This simulation would convince me if I were among the skeptical students.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

C) There are better methods than simulation to convince skeptical students in this case.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

M6. You belong to a group of students taking a course in modern physics. In class, the teacher mentions a fact which seems counter-intuitive to the students. It concerns time dilation in the theory of Relativity. Many students are skeptical. The teacher thus decides to illustrate the problem with a computer simulation.

At the beginning, the *computer simulation* shows three identical very precise clocks, side by side. The three clocks are perfectly synchronized. Then, the first clock is seen to travel around the world aboard a jet plane which has the world record for speed, while the other two clocks remain on earth. Finally, the three clocks are gathered together in order to compare the time given by each of them. The result: the clocks that remained on earth are still perfectly synchronized with each other. However, the one that went around the world at great speeds indicates slightly lesser time (the difference is infinitesimal). The simulation clearly shows this result.

A) Approximately estimate the percentage of skeptical students in the class which, in your opinion, would be completely convinced by this simulation.

☐ 0% ☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ 60% ☐ 70% ☐ 80% ☐ 90% ☐ 100%

Circle the number which corresponds to your opinion regarding the following propositions:

B) This simulation would convince me if I were among the skeptical students.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

C) There are better methods than simulation to convince skeptical students in this case.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

- - - - - - - - - -

M7. A scrapyard employee must operate a special jib crane for the first time. This special jib crane is used both to move and crush unusable materials at the same time, in one single operation. The *sole* training that the employee will undergo before operating the special crane will be done with a *computer simulation* (a simulation of the special jib crane and of various unusable materials).

A) Indicate the level of confidence that should be granted to this employee, in your opinion.

1 – very low 2 – low 3 – moderate 4 – high 5 – very high

Circle the number which corresponds to your opinion regarding the following propositions:

B) The employee could commit grave errors when carrying out his work.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

C) The employee is well prepared for various sorts of difficulties when carrying out his work.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

M8. A new employee in a nuclear power plant is substituting for other employees on strike. Without help from anyone, he must monitor the state of a nuclear reactor and perform a diagnostic in case of a problem. It is the first time that he is monitoring a nuclear reactor. The *sole* training that he has undergone consisted in the monitoring and diagnostic of a *computer simulation* of the nuclear reactor in question.

A) Indicate the level of confidence that should be granted to this employee, in your opinion.

1 – very low 2 – low 3 – moderate 4 – high 5 – very high

Circle the number which corresponds to your opinion regarding the following propositions:

B) The employee could commit grave errors when carrying out his work.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

C) The employee is well prepared for various sorts of difficulties when carrying out his work.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

SEE NEXT PAGE FOR QUESTIONS M9 TO M12

*« **We would also like to have your opinion regarding the various instructional methods used in the following cases.** (Beware, the objective is not to have you solve the physics problems that are described in some of these situations ; in fact, the solutions to the problems are already given. Do not hesitate to ask questions in case you have a problem – that's what I'm here for!)*

M9. You belong to a group of students taking a course in modern physics. In class, the teacher mentions a fact which seems counter-intuitive to the students. It concerns time dilation in the theory of Relativity. Many students are skeptical. The teacher thus decides to illustrate the problem with a ***video clip***.

At the beginning, the *video clip* shows three identical very precise clocks, side by side. The three clocks are perfectly synchronized. The first clock is then seen to travel around the world aboard a jet plane which has the world record for speed, while the other two clocks remain on earth. Finally, the three clocks are gathered together in order to compare the time given by each of them. The result: the clocks that remained on earth are still perfectly synchronized with each other. However, the one that went around the world at great speeds indicates slightly lesser time (the difference is infinitesimal). The video clip clearly shows this result.

A) Approximately estimate the percentage of skeptical students in the class which, in your opinion, would be completely convinced by this video clip.

☐ 0% ☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ 60% ☐ 70% ☐ 80% ☐ 90% ☐ 100%

Circle the number which corresponds to your opinion regarding the following propositions:

B) This video clip would convince me if I were among the skeptical students.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

C) There are better methods than a video clip to convince skeptical students in this case.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

----

M10. You belong to a group of students taking a «Mechanics 101» physics course (dealing with dynamics). At the beginning of class, the teacher mentions a fact which seems counter-intuitive to the students. Many students are skeptical. The teacher thus decides to illustrate the problem with a ***video clip***.

The *video clip* shows a wooden cube floating (due to the absence of gravity) in the cockpit of the space shuttle, which is orbiting the earth . A tennis ball is twice launched on the wooden block, which has a Velcro covering on one of its faces.

In the first case, the tennis ball is launched on the face of the cube covered with Velcro, and the ball sticks to the cube after the collision.

In the second case, the ball is launched on a cube face **not** covered in Velcro, and thus the ball **bounces off** the cube after the collision. (A special device allows launching the ball at the same speed in both cases.)

The speed of the cube after collision is compared between the two cases. The result: The speed of the wooden cube is greater in the case where the ball **bounces off** the face of the cube not covered in Velcro. The video clip clearly shows this result.

A) Approximately estimate the percentage of skeptical students in the class which, in your opinion, would be completely convinced by this video clip.

☐ 0% ☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ 60% ☐ 70% ☐ 80% ☐ 90% ☐ 100%

Circle the number which corresponds to your opinion regarding the following propositions:

B) This video clip would convince me if I were among the skeptical students.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

C) There are better methods than a video clip to convince skeptical students in this case.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

- - - - - - - -

M11 A scrapyard employee must operate a special jib crane for the first time. This special jib crane is used both to move and crush unusable materials at the same time, in one single operation. The *sole* training that the employee will undergo before operating the special crane *will be done by using a more simple crane to move the materials, as well as a different device that crushes these materials in a way that is very similar to the special jib crane*.

A) Indicate the level of confidence that should be granted to this employee, in your opinion.

1 – very low 2 – low 3 – moderate 4 – high 5 – very high

Circle the number which corresponds to your opinion regarding the following propositions:

B) The employee could commit grave errors when carrying out his work.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

C) The employee is well prepared for various sorts of difficulties when carrying out his work.

1- disagree very strongly 2 – disagree 3 – uncertain 4 – agree 5 – agree very strongly

M12. A new employee in a nuclear power plant is substituting for other employees on strike. Without help from anyone, he must monitor the state of a nuclear reactor and perform a diagnostic in case of a problem. It is the first time that he is monitoring a nuclear reactor. The *sole* training that he has undergone consisted in the monitoring and diagnostic of *other devices that work in a way that is very similar to the nuclear reactor in question* .

A) Indicate the level of confidence that should be granted to this employee, in your opinion.

1 – very low   2 – low   3 – moderate   4 – high   5 – very high

Circle the number which corresponds to your opinion regarding the following propositions:

B) The employee could commit grave errors when carrying out his work.

1- disagree very strongly   2 – disagree   3 – uncertain   4 – agree   5 – agree very strongly

C) The employee is well prepared for various sorts of difficulties when carrying out his work.

1- disagree very strongly   2 – disagree   3 – uncertain   4 – agree   5 – agree very strongly

B.2 Values for indicators of a priori attitudes toward simulation, as computed from questionnaire answers

Table B.1 (which corresponds to the left half of table 1 in the main document [table A.6 in Appendix A]) contains indicator values for *a priori* attitudes toward simulation in comparison to video, when used to illustrate physics concepts. These were obtained by comparing question M5 responses to question M10 responses (see above) which both involved a mechanics concept, as well as by comparing question M6 responses to question M9 responses which both involved a relativity concept. The scale of the indicators ranges from –20 to +20. Negative values indicate unfavorable attitudes toward simulation. Positive values indicate favorable attitudes to*ward simulation.*

In the main document (table 1) and Appendix A (table A.6), the following symbols were used for specific ranges of values :

– – : - 20 to - 12 (a strong unfavorable attitude toward simulation)

– : - 11 to - 4 (a moderately unfavorable attitude toward simulation)

0 : - 3 to + 3 (a neutral attitude toward simulation)

\+ : + 4 to + 11 (a moderate tendency to favor simulation)

++ : +12 to + 20 (a strong tendency to favor simulation)

Table B.1: **A priori** ***attitudes toward simulation (in comparison to video) when used to illustrate physics concepts***

Subjects \ Questions		Simulation is used to convince skeptical students of validity of counter-intuitive **classical mechanics concept (M5-M10)**			Simulation is used to convince skeptical students of validity of counter-intuitive **relativity concept (M6-M9)**		
		A) Convince *skeptical classmates*	*B) Convince subject*	*C) Quality of method*	A) Convince *skeptical classmates*	*B) Convince subject*	*C) Quality of method*
Chemistry	AN	0	**- 5**	0	0	0	0
	BO	0	0	5	0	0	0
	CP	0	5	5	0	0	0
	DQ	**- 4**	**- 5**	**- 5**	**- 2**	**- 5**	**- 5**
	ER	**- 2**	0	0	**- 2**	**-10**	0
Mechanical Engineering	FS	**-10**	0	**- 5**	**- 2**	0	0
	GT	0	5	0	**- 4**	**- 5**	**-10**
	HU	**-8**	**-5**	**-10**	**- 8**	**-10**	**- 5**
	IV	**- 2**	**- 5**	0	**- 6**	**- 5**	0
Physics	JW	**- 2**	0	**- 5**	**-2**	0	5
	KX	**-12**	**-10**	**- 5**	**-16**	**- 20**	**- 5**
	LY	4	0	10	0	0	10
	MZ	**- 8**	**- 5**	**-10**	**- 6**	0	0

Table B.2 (which corresponds to the right half of table 1 in the main document [table A.6 in Appendix A]) presents indicator values for *a priori* attitudes toward simulation, in comparison to use of real equipment (though simpler than the one needed for the actual task), in skill training. These indicators were obtained by comparing question M7 responses to question M11 responses (see above) which both involved training for a low risk mechanical operation, as well as question M8 responses to question M12 responses, which both involved training for a high risk computer-based task. The scale of the indicators ranges from –20 to +20. Negative values indicate unfavorable attitudes toward simulation. Positive values indicate favorable attitudes toward simulation.

In the main document (table 1) and Appendix A (table A.6), the following symbols were used for specific ranges of values :

– – : - 20 to - 12 (a strong unfavorable attitude toward simulation)

– : - 11 to - 4 (a moderately unfavorable attitude toward simulation)

0 : - 3 to + 3 (a neutral attitude toward simulation)

\+ : + 4 to + 11 (a moderate tendency to favor simulation)

++ : +12 to + 20 (a strong tendency to favor simulation)

Table B.2: A priori attitudes toward simulation (in comparison to real but simpler equipment) in the context of skill training

Subjects \ Questions		Simulation is used to train operator for **scrapyard task (M7-M11)** (low risk / mechanical operation)			Simulation is used to train operator for **nuclear reactor task (M8-M12)** (high risk / computer-based)		
		A) General level of confidence in operator	*B) Operator (not) prone to commit grave errors*	*C) Operator prepared for difficulties*	*A) General level of confidence in operator*	*B) Operator (not) prone to commit grave errors*	*C) Operator prepared for difficulties*
Chemistry	AN	0	0	**- 5**	0	0	5
	BO	**- 5**	5	0	0	10	10
	CP	10	10	15	10	10	10
	DQ	**- 5**	**- 5**	**- 5**	**- 5**	**- 5**	**-10**
	ER	0	0	**- 5**	5	5	5
Mechanical Engineering	FS	0	0	**- 5**	5	10	5
	GT	5	5	**-5**	**- 5**	0	0
	HU	0	**-5**	0	**-10**	**-10**	**-10**
	IV	0	10	10	5	10	10
Physics	JW	0	0	0	0	0	0
	KX	10	10	10	10	10	15
	LY	0	0	5	0	5	5
	MZ	0	0	5	0	0	0

B.3 Original Questionnaire (in french)

« Il nous serait utile de connaître votre avis au sujet de différentes méthodes pédagogiques employées dans les cas suivants. Pour chacune des mises en situation veuillez répondre aux trois questions. *(Attention, il ne s'agit pas de résoudre les problèmes de physique qui sont décrits dans certaines de ces mises en situation ; d'ailleurs, la solution des problèmes est donnée. N'hésitez pas à me poser des questions en cas de besoin, je suis là pour ça !)*

M5. Vous faites partie d'un groupe d'étudiants qui prennent le cours de physique «Mécanique 101» (c'est un cours de dynamique). En début de classe, le professeur mentionne un fait qui paraît contre-intuitif aux yeux des étudiants. Plusieurs étudiants sont sceptiques. Le professeur décide donc d'illustrer le problème à l'aide d'une *simulation informatique*.

La *simulation informatique* montre un cube de bois qui flotte (en l'absence de gravité) dans la cabine de la navette spatiale en orbite autour de la terre. Une balle de tennis est lancée à deux reprises sur le cube de bois, dont une des faces a été recouverte de Velcro.

Dans un premier cas, la balle de tennis est tirée sur la face du cube couverte de Velcro, et la balle **colle** au cube après la collision.

Dans le deuxième cas, la balle est tirée sur une face du cube qui **n'est pas** couverte de Velcro, et donc la balle **rebondit** après la collision. (Un appareil spécial permet de lancer la balle à la même vitesse dans les deux cas.)

On compare la vitesse du cube de bois après la collision dans les deux cas. Résultat : La vitesse du cube de bois est plus grande dans le cas où la balle **rebondit** sur la face du cube qui n'est pas couverte de Velcro. La *simulation informatique* montre clairement ce résultat.

A) Estimez approximativement la proportion des étudiants sceptiques dans la classe qui, d'après vous, seraient complètement convaincu par cette simulation.

☐0% ☐10% ☐20% ☐30% ☐40% ☐50% ☐60% ☐70% ☐80% ☐90% ☐100%

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) Cette simulation me convaincrait si je faisais partie des étudiants sceptiques.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

C) Il existe de meilleures méthodes que la simulation pour convaincre les étudiants sceptiques dans ce cas.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

M6. Vous faites partie d'un groupe d'étudiants qui prennent un cours de physique moderne. En classe, le professeur mentionne un fait qui paraît contre-intuitif aux yeux des étudiants. Il s'agit de la dilatation du temps dans la théorie de la Relativité. Plusieurs étudiants sont sceptiques. Le professeur décide donc d'illustrer le problème à l'aide d'une simulation informatique.

Au début, la *simulation informatique* montre, côte à côte, trois horloges très précises et identiques. Les trois horloges sont exactement synchronisées. Ensuite, on voit que la première horloge fait le tour du monde à bord de l'avion à réaction qui détient le record mondial de vitesse et on voit que les deux autres horloges restent sur terre. Finalement, on réunit les horloges pour comparer le temps donné par chacune d'elles. Résultat : les horloges restées sur terre sont encore parfaitement synchronisées entre elles. Par contre celle qui a fait le tour du monde à grande vitesse indique un temps légèrement plus faible (il s'agit d'une différence infime). La simulation montre clairement ce résultat.

A) Estimez approximativement la proportion des étudiants sceptiques dans la classe qui, d'après vous, seraient complètement convaincu par cette simulation.

☐ 0% ☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ 60% ☐ 70% ☐ 80% ☐ 90% ☐ 100%

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) Cette simulation me convaincrait si je faisais partie des étudiants sceptiques.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

C) Il existe de meilleures méthodes que la simulation pour convaincre les étudiants sceptiques dans ce cas.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

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M7. Un employé d'une cour à ferraille doit opérer, pour la première fois, une grue mécanique spéciale. Cette grue spéciale sert à la fois à déplacer et à écraser des matériaux inutilisables, et ce, en une seule opération. Le *seul* entraînement qu'il subira avant d'opérer la grue spéciale se fera à l'aide d'une *simulation informatique* (simulation de cette grue mécanique spéciale et de divers matériaux inutilisables).

A) Indiquez le niveau de confiance qu'il faudrait accorder à cet employé, selon vous.

1 – très faible 2 – faible 3 – modéré 4 – élevé 5 – très élevé

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) L'employé pourrait faire de graves erreurs dans l'exercice de son travail.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

C) L'employé est bien préparé à affronter des difficultés de toutes sortes dans l'exercice de son travail.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

M8. Un nouvel employé d'une centrale nucléaire remplace d'autres employés en grève. Sans l'aide de personne, il doit surveiller l'état du réacteur nucléaire et faire son diagnostique en cas de problème. C'est la première fois qu'il surveille un vrai réacteur nucléaire. Le *seul* entraînement qu'il a subi, a consisté à diagnostiquer et à surveiller une *simulation informatique* du réacteur de la centrale nucléaire en question.

A) Indiquez le niveau de confiance qu'il faudrait accorder à cet employé, selon vous.

1 – très faible   2 – faible   3 – modéré   4 – élevé   5 – très élevé

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) L'employé pourrait faire de graves erreurs dans l'exercice de son travail.

1- tout à fait en désaccord   2 – en désaccord   3 – incertain   4 – d'accord   5 – tout à fait d'accord

C) L'employé est bien préparé à affronter des difficultés de toutes sortes dans l'exercice de son travail.

1- tout à fait en désaccord   2 – en désaccord   3 – incertain   4 – d'accord   5 – tout à fait d'accord

SEE NEXT PAGE FOR QUESTIONS M9 TO M12

M9. Vous faites partie d'un groupe d'étudiants qui prennent un cours de physique moderne. En classe, le professeur mentionne un fait qui paraît contre-intuitif aux yeux des étudiants. Il s'agit de la dilatation du temps dans la théorie de la Relativité. Plusieurs étudiants sont sceptiques. Le professeur décide donc d'illustrer le problème à l'aide d'une ***séquence vidéo***.

Au début, *la séquence vidéo* montre, côte à côte, trois horloges très précises et identiques. Les trois horloges sont exactement synchronisées. Ensuite, on voit que la première horloge fait le tour du monde à bord de l'avion à réaction qui détient le record mondial de vitesse et on voit que les deux autres horloges restent sur terre. Finalement, on réunit les horloges pour comparer le temps donné par chacune d'elles. Résultat : les horloges restées sur terre sont encore parfaitement synchronisées entre elles. Par contre celle qui a fait le tour du monde à grande vitesse indique un temps légèrement plus faible (il s'agit d'une différence infime). La séquence vidéo montre clairement ce résultat.

A) Estimez approximativement la proportion des étudiants sceptiques dans la classe qui, d'après vous, seraient complètement convaincu par cette simulation.

☐ 0% ☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ 60% ☐ 70% ☐ 80% ☐ 90% ☐ 100%

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) Cette simulation me convaincrait si je faisais partie des étudiants sceptiques.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

C) Il existe de meilleures méthodes que la simulation pour convaincre les étudiants sceptiques dans ce cas.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

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M10. Vous faites partie d'un groupe d'étudiants qui prennent le cours de physique «Mécanique 101» (c'est un cours de dynamique). En début de classe, le professeur mentionne un fait qui paraît contre-intuitif aux yeux des étudiants. Plusieurs étudiants sont sceptiques. Le professeur décide donc d'illustrer le problème à l'aide d'une ***séquence vidéo***.

La séquence vidéo montre un cube de bois qui flotte (en l'absence de gravité) dans la cabine de la navette spatiale en orbite autour de la terre. Une balle de tennis est lancée à deux reprises sur le cube de bois, dont une des faces a été recouverte de Velcro.

Dans un premier cas, la balle de tennis est tirée sur la face du cube couverte de Velcro, et la balle **colle** au cube après la collision.

Dans le deuxième cas, la balle est tirée sur une face du cube qui ***n'est pas*** couverte de Velcro, et donc la balle **rebondit** après la collision. (Un appareil spécial permet de lancer la balle à la même vitesse dans les deux cas.)

On compare la vitesse du cube de bois après la collision dans les deux cas. Résultat : La vitesse du cube de bois est plus grande dans le cas où la balle **rebondit** sur la face du cube qui n'est pas couverte de Velcro. La séquence vidéo montre clairement ce résultat.

A) Estimez approximativement la proportion des étudiants sceptiques dans la classe qui, d'après vous, seraient complètement convaincu par cette simulation.

☐ 0% ☐ 10% ☐ 20% ☐ 30% ☐ 40% ☐ 50% ☐ 60% ☐ 70% ☐ 80% ☐ 90% ☐ 100%

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) Cette simulation me convaincrait si je faisais partie des étudiants sceptiques.

1- tout à fait en désaccord 2 – en désaccord 3 – incertain 4 – d'accord 5 – tout à fait d'accord

C) Il existe de meilleures méthodes que la simulation pour convaincre les étudiants sceptiques dans ce cas.

1- tout à fait en désaccord   2 – en désaccord   3 – incertain   4 – d'accord   5 – tout à fait d'accord

M11. Un employé d'une cour à ferraille doit opérer, pour la première fois, une grue mécanique spéciale. Cette grue spéciale sert à la fois à déplacer et à écraser des matériaux inutilisables, et ce, en une seule opération. Le *seul* entraînement qu'il subira avant d'opérer la grue spéciale *se fera en se servant d'une grue plus simple pour déplacer les matériaux et aussi d'un appareil différent qui écrase les matériaux de façon très semblable à la grue spéciale.*

A) Indiquez le niveau de confiance qu'il faudrait accorder à cet employé, selon vous.

1 – très faible   2 – faible   3 – modéré   4 – élevé   5 – très élevé

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) L'employé pourrait faire de graves erreurs dans l'exercice de son travail.

1- tout à fait en désaccord   2 – en désaccord   3 – incertain   4 – d'accord   5 – tout à fait d'accord

C) L'employé est bien préparé à affronter des difficultés de toutes sortes dans l'exercice de son travail.

1- tout à fait en désaccord   2 – en désaccord   3 – incertain   4 – d'accord   5 – tout à fait d'accord

M12. Un nouvel employé d'une centrale nucléaire remplace d'autres employés en grève. Sans l'aide de personne, il doit surveiller l'état du réacteur nucléaire et faire son diagnostique en cas de problème. C'est la première fois qu'il surveille un vrai réacteur nucléaire. Le *seul* entraînement qu'il a subi, a consisté à diagnostiquer et à surveiller *d'autres appareils qui fonctionnent de manière très semblable au réacteur nucléaire en question.*

A) Indiquez le niveau de confiance qu'il faudrait accorder à cet employé, selon vous.

1 – très faible   2 – faible   3 – modéré   4 – élevé   5 – très élevé

Encerclez le chiffre qui correspond à votre opinion au sujet des propositions suivantes :

B) L'employé pourrait faire de graves erreurs dans l'exercice de son travail.

1- tout à fait en désaccord   2 – en désaccord   3 – incertain   4 – d'accord   5 – tout à fait d'accord

C) L'employé est bien préparé à affronter des difficultés de toutes sortes dans l'exercice de son travail.

1- tout à fait en désaccord   2 – en désaccord   3 – incertain   4 – d'accord   5 – tout à fait d'accord

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APPENDIX C: RESULTS PRESENTED AS INDIVIDUAL CASE DESCRIPTIONS

C.1 Individual case descriptions: outstanding elements pertaining to credibility judgments and verisimilitude cues

Below, we present separate observations for each subject: that is, the outstanding elements of each subject's verisimilitude judgments, and cues related to these judgments. The following exposition should actually be seen as thirteen fairly thorough case descriptions.

These individual accounts are very important because they allow us to preserve the level of basic description required for a multi-case study: they offer a more focused view of the specific credibility concerns deemed important for each of the 13 participants. When possible, judgments are presented in their original context, with important nuances related therein. We invite the interested reader to consult these accounts in order to have a better idea of how various verisimilitude judgments and cues relate to each other within a specific individual session, and to obtain further details concerning specific judgments.

It would be very useful to read a subject's profile (which can be found in Appendix A) just before reading the individual account which concerns him.

C.1.1 Subjects AN, BO, CP, DQ, ER: chemistry students

Subject AN

When AN was asked what he [82] thought of the VPLab compared to his previous lab experiences, he said that it was very realistic. The main element which contributed to this favorable judgment was the disk's motion (see below).

Lack of tangibility / Evaluation of the VPLab's potential to allow performing educational experiments

During the debriefing interview, AN was required to evaluate the software's potential to allow performing physics experiments. We noticed that AN rated the VPLab's potential differently when he considered different pedagogical objectives:

> ***Interviewer****: To allow someone to develop abilities relating to manipulation [of apparatus], to [the application of a] method, to rigour, and accounting for things that can happen in a lab…*
>
> ***AN****: Well, then maybe [you could push it] further. There's one dimension that is the comprehension of concepts and another dimension that is manual experimentation. On one hand, to help you understand [concepts], this is fine… but on the other hand, to personally perform experiments, then I think that a real lab is necessary.*

[82] Masculine pronouns and adjectives are used for both male and female subjects. As a precaution, we have chosen to conceal gender in order to inhibit unwarranted associations between certain attitudes and gender.

***Interviewer**: To help you understand, it's fine but to experiment, not really…*

***AN**: No.* [citation 39]

AN believed that the VPLab had more potential to help "understand concepts" – for which he gave a rating of 5 on a 5 point scale – and a little less potential for acquiring skills ("manual experimentation") – for which he gave a rating of 3 or 4 on a 5-point scale. Notice that this runs counter to his preconceived ideas: AN's profile shows that his preconceived ideas in regards to simulation were such that this medium was less appropriate in the context of learning physics concepts and more appropriate in the context of training (acquiring skills).[83] In any case, we would conclude from this that pedagogical objectives can serve as criteria to which users can refer when performing judgments of verisimilitude.

It seems that the VPLab's most important flaw, in AN's opinion, is its lack of "palpability", i.e., that working with the VPLab is not enough of a tangible experience. The subject stated that the VPLab needed to have a more "palpable" quality to it, if it was to have a better potential for experimentation and that "maybe putting it in 3D could help" [citation 40]. We could also conclude from this that a possible cue for verisimilitude is the graphical complexity of the environment (in this case 2D vs. 3D graphics).

Verisimilitude of the disk's motion on the air-table

In AN's case, the primary cue for verisimilitude was the unpredictability of the disk's motion. This is probably related to AN's observation of the disk's motion after he had launched it very precisely in one corner of the table: after going back and forth twice across the diagonal of the rectangular table, points of impact with the table's sides started to get away from the corners and collisions started to occur at different places on the sides of the table.

Also, the fact that the disk slowed down after having been launched gave the subject an indication that there was residual friction at work against the disk's motion. This yielded greater verisimilitude: [84]

***AN**: […] air must be [acting] on it, so it [the disk] will eventually stop…*

***Interviewer**: You think it'll eventually stop ?*

***AN**: Yes [..] because the pump eliminates a certain type of friction but not all of it.*

***Interviewer**: What do you think about the fact that we still included some friction ?*

***AN**: Well, I would say it's truthful. Very realistic.*

***Interviewer**: And is that necessarily a good thing or would you say that it is not important ?*

***AN**: Yes, it's important. You have to try to get as close to reality as possible when you experiment in physics because… If you take away many real conditions, you'll end up with a theory that is applicable only within your own conditions.* [citation 41]

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[83] One way to explain this apparent contradiction is to point out that, when he answered the questionnaire before interacting with the VPLab, AN had imagined more complex 3D simulators in the context of training (indeed, he mentioned these types of environments when he commented his questionnaire answers). It is not so surprising then that he would find the VPLab (a 2D environment) less adequate for the purpose of acquiring experimental skills. Supporting this hypothesis is AN's suggestion of making the VPLab a 3D environment.

[84] Observe that the video clip does not depict the disk's motion long enough for the subject to witness this deceleration when watching the video.

Another important finding in this area is that AN was able to discern visual presentation of the disk's motion from its model. When watching the disk's jerky motion [85], as it was supposed to move extremely slowly, AN proposed that the software didn't allow for smooth presentation of the motion and that the jerky movement was really representing slow movement. He said that this was just a detail that did not bother him. This is a case where visual fidelity (and, more importantly, *perceived* visual fidelity) is poor but credibility is preserved.

Mastery over the simulation deduced from free manipulation and comparisons between the video clip (of the disk moving on the actual air-table) and the simulation

AN felt that it was stimulating to have mastery over objects in the simulation. He claimed that the simulation's graphical attributes (compared to the video image's attributes) were a sign that he "would be the protagonist [in the simulation]" exactly like the experimenters depicted in the video clip comprised in the multimedia explanations. [citation 42] We can also infer from this quote that the video clip was a referent for the simulated experiment. Later, when he first interacted with the simulation, AN further deduced that he was "master" of the situation (i.e., that he had to move objects himself) when he noticed that the disk wasn't automatically brought back to its initial position after getting stuck in a corner of the table.

Multimedia explanations of the experiment

The textual and graphical explanations of the simulation contained in the multimedia Presentation workspace helped to stabilize the meaning of the visual simulation and they provided details on the behavior of its objects as well as information on actions that are possible within the simulation. [86] AN seemed to have understood some of the simulation's features (the role of the pump in suppressing friction on the table, more specifically) by consulting the multimedia explanations; hence, the disk's behavior was more understandable and coherent. As such, the explanations in the multimedia workspaces, be they of an introductory or theoretical nature, must be considered as cues for verisimilitude.

Use of a scale factor to establish a correspondence between images displayed on the Analysis workspace's monitor and the simulation in the Manipulation workspace.

In the Analysis workspace, AN used the ruler to measure the 'filmed' image of a marker on which was written "20 cm".[87] The fact that the measure he obtained on the monitor was

[85] This effect was not the result of the physical model of the disk's motion. Instead, the disk's jerky motion (when extremely slow) was the result of intrinsic display limitations

[86] It is important to note that subjects may still not be able to correctly identify objects after seeing the multimedia explanations. For example, AN continued to think that the disk was a ball after he had seen the multimedia explanations (the user has a bird's eye view of the simulated objects so that the disk may be easily mistaken for a ball, at first sight). Also interesting is the fact that this had no apparent adverse effects on the verisimilitude of this object's behavior.

[87] The interviewer required him to do so.

smaller than 20 cm established a scale correspondence to the Manipulation workspace simulation and it seemed to make the metaphor coherent; it may have also conferred a different reality status to the Manipulation workspace:

> ***Interviewer****: When you saw the 20 centimeter marker, what did that suggest ?*
>
> ***AN:*** *20 centimeters in reality [he emphasized the word "reality"]. But now, you've transposed that to the monitor.* [citation 4***3***]

Verisimilitude of the experimental method / Requiring the subject to perform uncertainty assessment

During the debriefing interview, AN was asked if the VPLab's objects could be replicated in an actual lab and he answered that they could. He also said that it was possible, in an actual lab, to accomplish the actions that he had performed in the VPLab.

On the other hand, it may be significant in itself that, when asked, AN was unable to come up with points of comparison between how work was done within the VPLab and how it is done in an actual lab. However, when required to evaluate the probability of finding a similar way of carrying out measurements in a lab, the subject said it was probable (4 on a 5-point scale). [88] Moreover, we have reason to believe that asking AN to perform uncertainty assessment was itself a cue for verisimilitude:

> *[..] 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.* [citation 20]

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 subjects to assess uncertainty if the interface, and more specifically the measuring instruments, afford it.) It is interesting to note that at first, AN thought that there would be some function which would allow him to automatically obtain uncertainty of measurement.

Expectations of much lower complexity compared to reality and of less variation in results
when repeating experiments

As we saw in his profile section (see Appendix A), AN had been aware that results may vary from trial to trial when repeating an experiment in an actual lab and that statistical methods may be used to compile results of multiple trials. It would seem that AN did not expect experimental results to vary as much with the VPLab because he believed that many elements would be missing in the simulation since a human being had programmed it.

Subject BO

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[88] The condition AN set for this positive rating was that the (virtual) tape measure be replaced by a ruler. AN thought that the tape measure was less plausible – three elements seem to contribute to this: first, the tape measure had a digital display; second, it seemed bizarre for him to pull on what he perceived to be a string (instead of a wider tape) in order to measure; and third, the measurement was taken starting at a red circle drawn on the tape measure's plexi-glass casing (and so he could not imagine how the measurement would be processed by the tape measure if it were real).

Importance of verisimilitude

Subject BO spontaneously expressed how important the problem of verisimilitude is for users: [89]

> *Because the most important obstacle for software may be that people will always think that things have been pre-arranged, like special effects in a movie. They will say: "Well they've arranged it so it's just right." So this is the advantage of having video as a complement. You can see that it hasn't been pre-arranged.* [citation 44]

From this excerpt, we also get the idea that the video clip (as part of the experiment's multimedia Presentation workspace) may have been an important cue for verisimilitude, hence playing a big role in promoting credibility. We will come back to this topic later.

Evaluation of the VPLab's potential to allow performing educational experiments / The question of "tangibility"

BO assessed the VPLab's potential to allow performing educational experiments, and its likeness to experimental reality. Using a 5-point scale (with 1 signifying 'a very low potential' and 5 signifying 'a very high potential'), BO rated the VPLab between 4 and 5, saying that it was "*almost identical to the real motion* [the real phenomenon]." [citation 45] Nonetheless, having worked on an actual air-table, he felt that the VPLab could not completely replace the actual experiment because the experience of working on the VPLab was far less tangible. He compared the VPLab to looking at a picture of someone famous and likened performing the actual experiment to shaking that person's hand in "real life." "You may appreciate the picture," he said, "but you'll appreciate his presence [even more]."

BO's attitude illustrates some of the subtle nuances that distinguish presence – the quality that seems to be lacking here – from verisimilitude. In this case at least, verisimilitude can apparently subsist despite diminished presence.[90]

Direct manipulation coupled with a high degree of control over objects and choice of methods

The fact that much free interaction with the VPLab's graphical objects is allowed was something that reminded subject BO of video games he had played. One might expect that this likeness to video games would not favor verisimilitude. Just the opposite, free

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[89] Of course, this subject could have inferred that credibility was an important issue after answering questions dealing with credibility in the preliminary questionnaire.

[90] Lack of presence, for this subject, seems to be linked to lack of "tangibility" but also to the fact that a virtual lab's images are computer-generated. Surprisingly though, BO stated that he would NOT be inclined to give a higher rating to an experiment performed within a complex immersive environment (of course, knowledge of such technologies is probably obtained through media and subjects were not given the possibility to inspect one first-hand, so this kind of statement has to be taken with some caution.) When asked why, BO had this to say:

> *Well, because it's still numerical – the images are drawn or made with a computer. But if you see it… You know, if you see someone in weightlessness on television, it's not the same as actually being in weightlessness yourself.* [citation 46]

We also deduce from this that watching photo-realistic images is also an experience that lacks presence, in BO's opinion.

interaction – a high degree of control over objects and choice of methods – coupled with 'direct manipulation' conventions was precisely the most important cue for greater verisimilitude: [91]

> *[If] you do not have control over anything [and you follow some pre-established path], 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.* [citation 2]

The video clip

For this subject (as for others) the video clip of the actual apparatus being used, coupled with references to the place where it was filmed, seems to have been a very important cue for verisimilitude:

> ***Interviewer****: So this [video clip] is important ?*
>
> ***B.O:*** *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 experiment done with real objects.* [citation 8]

Hence, the video clip functions as a referent for the simulation:

> ***BO****: 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 of 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.* [citation 9]

It is noteworthy that BO tried to imitate some of the actions performed by the man who was depicted handling the disk in the video clip; we conclude that the clip may also function as reference for the *experimenter's behavior*.

Graphical attributes

Since video clips are cues for verisimilitude, one may ask if a visual simulation's graphical attributes are also cues. Though the simulation's graphics, once again, reminded BO of video games, he did not seem to think less of the VPLab – quite the contrary, in fact. [92] In his opinion, possible lack of credibility didn't have much to do with graphical attributes and was rather linked to people's perception of the nature of software and resistance to learning

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[91] Predictably, BO was not surprised when encountering limitations to interaction if he deemed that actions which were not allowed, such as dropping the disk beside the air-table on the merry-go-round's floor, were also somewhat useless in the context of an experiment.

[92] Concerning the graphics, this is what BO had to say:

> ***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.* [citation 13]

through this means: he called this the "software taboo". We wish to add that graphical quality may have made little difference for this particular subject, because he was not comparing the VPLab to other applications with more sophisticated graphics.

Verisimilitude of the disk's motion on the air-table

BO stated that the disk's motion on the air-table was "quite similar to the motion you would obtain on the real [apparatus]" [citation 47]. In this area, cues for verisimilitude were: "**Conservation of momentum**", "**uniform deceleration" after collisions** with the sides of the table, **and angles of collision which were similar to those "on a billiards table"**.[93] When evaluating the disk's motion, BO said he relied on his prior experience using an air-table.

The VPLab's main metaphor (virtual camcorder, virtual monitor and its Zoom and Trace functions)

Even though he had never used an actual camcorder, BO did compare use of the VPLab's virtual camcorder to possible use of an actual camcorder, for the purpose of filming trajectories in the context of a lab experiment. When referring to his own experience, he felt that *use* of the Analysis Workspace's monitor and camcorder [94] was very different from his prior *use* of rapid photography to collect and analyze data. First of all, he claimed, with photography one can't "play back" the recording and see what's going on at a specific instant, as is possible with the virtual camcorder. Second, with photography, the experimenter is constrained by a basic time interval between snapshots, so that in the analysis phase, he doesn't have the flexibility to modify the time interval between successive disk 'traces', as is seemingly possible with the monitor's *Trace* function.[95]

On the other hand, BO also stated that the VPLab's workspace was credible because, as with a real lab experiment, dots of some sort could be used as data. This was a good cue for verisimilitude. Of chief importance is the fact that differences observed by BO did not seem to have adverse effects in terms of verisimilitude. Based on comments made by BO, these differences had a negligible negative impact on verisimilitude because the basic functions of the devices (i.e., what the devices were used for) were the same.

When he zoomed in on the images displayed on the virtual monitor, BO observed that the traces were not identical. The distortion that caused differences among traces was in fact intentionally included by designers to simulate the limited resolution of existing camcorders and, at the same time, to promote uncertainty assessment– instead, BO believed

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[93] It is of interest to note that collision behavior on a billiards table is not as described in physics textbooks and not what it is commonly held to be (see Wallace, R.E., & Schroeder, M.C. [1988]. Analysis of billiard ball collisions in two dimensions. *American Journal of Physics*, 56 (9), 815-819). Hence, in spite of what some subjects might have thought, collision behavior on a billiards table cannot be assumed, *a priori*, to be the same as the collision behavior of a disc on an air-table.

[94] Offhand, BO was able to determine the Analysis workspace's function by noticing visual similarities between the camcorder and the monitor.

[95] Interestingly enough, even though there is a lower limit to the time interval associated with both the *Traces* and the virtual camcorder (the frame rate, if you will), subject BO did not explicitly make this parallel. He may just have felt that analyzing data within the VPLab's workspace was more dynamic and flexible by nature; hence this limitation was not identified clearly or was overlooked by BO.

that it was an unintentional computer artifact: he thought it had something to do with how pixels were being used. The subject did not seem overly bothered by the irregular traces because he felt that they would not have adverse consequences on measurements. He did mention, however, that this distortion effect following a zoom-in on the image reminded him that he was working on a computer.

Finally, we believe that BO's interpretation of the metaphor (a workbench used to perform measurements) might have at least slightly strayed from the meaning which designers had intended to convey. Although BO actually mentioned (during the debriefing interview) the analogy of recording an experiment with a camera and then watching the video replay, he also suggested (during the session) that writing on the Analysis workspace's display surface with a freehand-type function should be allowed.[96] Writing on a display monitor is not usually possible in reality.

Optimal conditions are expected because of the VPLab's nature

BO felt that subjects should be warned about simulated factors which would cause experimental results to radically stray from theoretical predictions (many, if not all subjects also said this, though not all for the same reasons.) If not told otherwise, BO would expect experimental conditions within the VPLab to be "optimal" because the VPLab is software.

Subject CP

Evaluation of the VPLab's potential to allow performing educational experiments / Impossibility of errors in handling apparatus

When evaluating the VPLab, CP claimed that it had a very high potential (a rating of 5 on a 5-point scale) to allow performing experiments. He stated one motive for such a high rating: the VPLab would avoid unplanned problems, physically caused by the apparatus or by errors in handling apparatus, that would disrupt the experiment and force the experimenter to start over (the example he gave was electrical discharges accidentally burning the carbon paper within a tracing system). Note that this may not be a good point with respect to verisimilitude. In any case, this subject showed much appreciation, overall, for the VPLab and seemed very satisfied with it.[97]

Not being able to get close to measuring instruments with graduations and lack of precision when measuring (because of visual alignment)

CP seemed to find it difficult to align graduated measuring instruments (like rulers and protractors) in order to get precise measurements. The subject also felt that he couldn't get as close to the measuring instrument (the ruler) as he wanted, because being too close to the screen was not optically comfortable. Strangely, had CP used the zoom functionality (which he knew about) in the Analysis workspace, getting physically closer to the screen would not have been as necessary. This not withstanding, the fact that it is less possible to

[96] Note however that in BO's opinion, the appearance of the display surface did not suggest that it was possible to write on it.
[97] For instance, CP commented favorably on the VPLab's graphical attributes.

get close to instruments is an important difference between the VPLab and real labs. (Subjects are sometimes reticent or forget to use the zoom functionality; perhaps the following section will shed some light on why.)

The VPLab's main metaphor (virtual camcorder, virtual monitor and its Zoom and Trace functions)

During the session, CP had interpreted the Analysis workspace's main display as a "screen" allowing him to see a replay "of the video sequence" he had recorded. The different color schemes used in the Manipulation and Analysis workspaces were cues for this interpretation.

Outstandingly, there was one requirement that CP found to be bothersome as he worked with the monitor in the Analysis workspace: when one measures distances between points on the virtual monitor's image, one has to factor in the scale of the image (which varies with the level of zoom) so that measurements are commensurate with the scale of reality as modeled within the simulation's framework. Judging from CP's comments, he must have felt that performing scale conversions of measurements did not correspond to anything that was part of lab work:

> *[…] but working with units and having to take into account [zoom-levels] 100%, 200%, 400% and having to translate those [units] to centimeters – I'm not used to this. When I'm in a lab, I work in centimeters and I can't get more than a 100% [real size] – I can't zoom-in on my apparatus.* [citation 48]

This frustration is understandable when we consider that this subject was not assessing the workspace in reference to a lab situation where working with different scales would be necessary (as with a real lab that would make use of cameras and video analysis tools).[98]

Interestingly, CP also seemed to think that working with scaled measurements would invalidate or render impossible certain operations like interpolating between graduations when measuring with the simulated ruler (the ruler was designed to replicate a real ruler and be used much the same way).

Because CP was using carbon paper markings as a referent for the *Trace* function (of the Analysis workspace), it seemed strange and impossible that there should be traces ahead of the object in motion (the disk's image) during playback. [99] The subject said this was not possible in a lab unless you had a computer to do it – by this, he probably meant '*unless you have a computer to predict or approximate the trajectory*'. Hence for subject CP, we believe that traces 'moving along' *ahead* of the object in motion is a cue which lead to lesser verisimilitude of the metaphor.

[98] We believe that the majority of students in Quebec would not have prior experience with such tools in a laboratory settings, and that CP's attitude may be common among them.

[99] It is essential to point out that the choice of experiment (one with an air-table) has consequences for verisimilitude judgments of the metaphor, and especially for those judgments which concern the Analysis workspace's *Trace* function. In educational labs, air-tables are often used in conjunction with a tracing system that works by repeatedly sending electrical discharges on carbon paper. Students analyze the trajectories of objects thus recorded on the carbon paper as a series of dots. Had we chosen a different experiment for this study – one that was not traditionally linked to such a tracing system – verisimilitude judgments of the *Trace* function might have been very different. Note, however, that the experiment was not chosen with this in mind.

Aside from the *Trace* function, CP felt that it was possible, although very costly, to replicate the metaphor in an actual lab by installing "a system of cameras" and by disposing of "a graphical interface on a computer" (presumably to analyze the recordings). [citation 49]

Precision and requiring subjects to perform uncertainty assessment

In CP's case, dissonance resulted from working on "*physics* software" like the VPLab which allowed for much less precision than that which is usually allowed in most computer-assisted tasks (for example, drawing with design software allows for much more precision). However, CP did acknowledge that uncertainty assessment was a normal part of physics experimentation:

> *Then again, in physics, it's not weird to have uncertainty [of measurement]: it's experimental. So it's normal to have uncertainty: we calculate it.* [citation 50]

This suggests that requiring (and allowing) subject CP to assess uncertainty was itself a cue for verisimilitude.

Types of instruments and types of objects being measured (distances between traces)

In CP's opinion, the types of instruments used during the session, the quantities measured (distances and angles) and the quantities derived (the disk's velocity) were very likely to be the same as in an actual lab experiment. Using traces of the disk, in the form of dots, as data was a cue for verisimilitude.[100]

The video clip

The video clip was used by this subject as a basis for verisimilitude judgments even though he did not have an unfavorable *a priori* attitude towards simulation (compared to video):

> *[…] it would be possible to reproduce it [reproduce a merry-go-round in a research lab] because we see in the video clip that they did it in Paris. It is possible to do it !* [citation 51]

Verisimilitude of the disk's motion on the air-table

CP seemed to be impressed by the disk's motion on the air-table, as he mentioned that building the simulation must have involved a lot of work. The fact that the disk decelerated after being launched gave the subject an indication that there was residual friction at work against the disk's motion:

> ***Interviewer****: What was happening before you stopped the pump ?*
>
> ***CP:*** *The disk was moving. It slowed down – there is a loss of speed, of course.*
>
> ***Interviewer****: Why ?*
>
> ***CP****: There is some friction; it's not totally absent.*
>
> ***Interviewer****: What do you think about the fact that there is friction ? Did you expect that ?*
>
> ***CP****: Well yes. Air creates friction. It is impossible [not to have friction] unless… We neglect it a lot [in calculations] but it's there all the same.*

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[100] This was also a cue in subject BO's case. Note, however, that BO did not have the same referent in mind as subject CP: he had measured distances between marks made on carbon paper created by electrical discharges, whereas BO had used an entirely different system which made use of rapid photography (see CP's profile in Appendix A).

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 discs so they slow down faster. I don't know if… [citation 10]

This suggests that the disk's deceleration (implying that air friction which worked against the disk's motion had been included in the simulation) was a strong cue for verisimilitude.

Results deviating slightly from theoretical predictions / Conditions that aren't ideal

CP believed that experimental results can and should usually deviate somewhat from theoretical predictions because experimental conditions are not perfect. He proposed that the VPLab should reflect this and not present ideal conditions. In contrast, he felt that if one performed the experiment correctly, results should come relatively close to theoretical predictions and not stray dramatically from them, which is what he had experienced in actual labs.

Impossibility of detecting degraded experimental conditions

During debriefing, CP was told that the simulation could have contained factors which would heavily degrade experimental conditions (soda dropped on the table making its surface sticky, for example). He reacted by saying that it would be impossible to detect this when using the software because users lacked the "physical feeling" of objects and the multiple points of view (seeing the table from many angles, for instance) that are helpful in detecting these types of degraded conditions in a lab. This suggests that, in the absence of specific cues allowing detection of anomalies, experimental outcomes that significantly stray from theoretical predictions would work against verisimilitude, in subject CP's case.

Subject DQ

Evaluation of the VPLab's potential to allow performing educational experiments

DQ gave the VPLab a rating of 4 on 5 for its potential to allow performing experiments. When asked why, DQ said that he saw the VPLab as an element that would bring students something distinct from lectures and regular lab work. He said that simulations were *complementary* to those means. When he was asked what the differences were between actual labs and the VPLab, DQ answered:

***DQ**: […] When you're on a computer, it's not real. I think that's the biggest difference between the two. When you're in a lab, you're the one who's manipulating, you're the one who's measuring, you're doing everything – when you're on a computer, you use the keys but you're not the one who's in control, you're not controlling, with your own hands, the things that you do.*

***Interviewer**: Right now, is that also the case ? It's a question of controlling things more directly with your own hands…*

***DQ:** For me, that's the big difference between software like this and a practical lab.*

***Interviewer**: What type of consequences does manipulating things with one's hands entail, compared to doing things like this [with the VPLab] ? Do you see repercussions on the experiment's results ? How does it change the way you do the experiment ?*

***DQ**: I think it doesn't give the same result. Ideally, in my opinion, you should be in a lab, but software like this can be a fine complement.*

> ***Interviewer**: Does manipulating things have an impact on what you can learn and the errors that you can make ?*
>
> ***DQ**: Sure, because [in a lab], if you make a mistake, if anything is wrong, you'll see it and you can readjust things. I think you have more control when… with equipment, when you're manipulating it. The disadvantage of a computer simulation is that you're not controlling everything. Even if you're controlling things with your keyboard and your mouse, it's not real – it's not the same.* [citation 3]

In our opinion, there are three issues to be addressed when considering the above excerpt.[101] We examine these below.

1) Difficulty in using the interface contrasted to ease of work in a lab

The first issue is a feeling of lack of control which may be caused or exacerbated by this subject's greater difficulties in using the VPLab's interface. If this feeling of lack of control is partly due to lack of skill, it could be lessened by allowing further interaction with the interface and by supporting the subject.

2) Less freedom, less control over objects and less ease in detecting problems which may occur during an experiment

The second issue is the more basic question of feeling that working with the VPLab entails less freedom and control over objects than in a real lab and less ease in detecting problems which may occur. This feeling is probably expressed by the following phrase: "[in a lab], if you make a mistake, if anything is wrong, you'll see it and you can readjust things." This feeling may well be directly related to two factors: (1) the fact that users do not directly touch objects with their hands when using the VPLab (this is explicitly referred to by DQ) ; and (2) the subject's suspicion that the nature of a 2D simulation does not allow users to detect potential anomalies.

3) Ontological status of the VPLab and unfavorable a priori attitudes toward simulation

Both of the factors we just stated should be less problematic, at least to some extent, in an immersive virtual environment. But consider the following excerpt:

> ***Interviewer**: Have you ever seen movies or news reports on virtual reality – of people who wear helmets and gloves ?*
>
> ***DQ**: Yes, I've seen that a few times.*
>
> ***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 [problem]. It remains imaginary… well, imaginary, in a way of speaking. It's not imaginary but it's not real.* [citation 4]

So the third issue is the even more basic question of ontology: the VPLab's experiment is computer generated and has no material substrate. In regards to this last issue, let's not forget, in comparison to other subjects, that DQ has quite an unfavorable *a priori* attitude

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[101] Notice that, contrary to DQ, other subjects like AN and BO felt rather in control of things and this feeling of mastery made things credible for them. This contrast in attitudes is very interesting but also difficult to explain.

toward simulation in the context of training (see table A.6 in Appendix A) and that this prejudice is probably at work here.

The VPLab's main metaphor: the Analysis workspace's Zoom and Trace functions / Use of a scale factor to establish a correspondence between the Analysis workspace's monitor and the simulation in the Manipulation workspace

In the Analysis workspace, DQ used the ruler to measure the 'filmed' image of a marker on which "20 cm" had been written. The fact that the measurement he obtained was smaller than 20 cm established a scale correspondence with the Manipulation workspace simulation and it seemed to make the metaphor coherent; it may have conferred a different reality status to the Manipulation workspace:

> ***Interviewer****: Why was " 20 cm" written on the purple marker ?*
>
> ***DQ****: Because it's the real space. And we're in a space that's… well, not virtual, but a space with a scale. So the scale would be that 1.1 centimeters is equivalent to 20 centimeters* ***in reality****. If we want to calculate, we can use this [scale] to transform…* [citation 52]

When asked to evaluate the probability of finding the Analysis workspace's features in a lab, DQ rated it at 3 on a 5 point scale (1 being a very low probability and 5 a very high probability): it did not seem likely that an actual lab could include the *Zoom* and *Trace* functions of the Analysis workspace. Concerning the *Trace* function, DQ said he could not imagine how one could add and remove traces at will so easily in the context of a real experiment.

Ideal conditions (appearance of flawlessness)

When the interviewer suggested the possibility of simulating factors that would cause experimental outcomes to stray from theoretical predictions, DQ answered that (if they existed) these factors would present difficulties also experienced in actual labs. He also claimed, that **due to the VPLab's appearance**, he would not have expected these factors to exist:

> *I would not have thought of that. [The VPLab] looks well built, very structured – it's going to work: nothing would go wrong.* [citation 53]

Subject ER

Graphical attributes and a narrow field of view

During the debriefing interview, ER was asked what he thought of the VPLab in comparison to the labs he had known:

> *As for realism, it is important to also have the opportunity to see the disk moving on an actual table, in an actual lab, because I'm not so sure that it enters into your head as much when you see it on a computer – it's not as convincing as when you see it for real".* [citation 54]

When asked to explain what was contributing to this sensation, the subject spoke about three elements. He first brought up the VPLab's instruments which, he said, "*were more or less real instruments*" (we will be discussing this shortly). Then he spoke of the colors (mentioning the blues, violets, and yellows [102]) of the simulation's objects which emphasized the fact that the simulation's images were drawings. To this, he added that the disk did not have the appearance of a real puck. Finally, he mentioned that seeing the apparatus in a narrow space was annoying and that it would be preferable to see the whole table in large.[103]

We conclude, as far as ER is concerned, that lower *visual fidelity* (through the cues described above) can be associated to lower verisimilitude.

Evaluation of the VPLab's potential to allow performing educational experiments

When evaluating the VPLab's potential to allow performing educational experiments, ER gave it a rating of 3 on a 5-point scale. He justified such a relatively low rating by the following argument:

> *I must admit that all the gadgets somewhat divert your attention from what you really should be doing – from the real phenomenon. It distances you a bit more from the physical phenomenon. You see it a bit like a game or a gizmo for drawing. It's more or less real and it… it's distracting.* [citation 55]

We shall try to expand on this comment in the sections below. For now, let us compare this excerpt with a comment ER made as he was exploring the Analysis workspace: [104]

> *I have to admit that I like this. […] I like this software – I enjoy performing physics experiments like this with instruments [like these].* [citation 56]

On the one hand, ER said that he enjoyed "performing *physics experiments*" with the virtual instruments and on the other, he felt that the VPLab's features distracted him from the main goal of the experiment.

"Real" and "unreal" instruments

ER was bothered by the fact that instruments which he perceived as "real" shared the environment with others which he perceived as "unreal". On one hand, the stopwatch, the protractor and the ruler seemed real to him, and on the other hand the calculator did not.[105]

We conclude that objects that were similar to those ER had seen, seemed more real to him than those that weren't. We also conclude that dissonance or lack of coherence occurred because both types of instruments were present in the same space.

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[102] Both the Manipulation and Analysis workspaces use specific color schemes comprised of vivid hues: 'warm' colors for the Manipulation workspace simulation and 'cool' colors (i.e., colors towards the blue/violet end of the spectrum) for the images displayed on the Analysis workspace monitor.

[103] When first exploring the Manipulation workspace, ER had tried to enlarge the air-table by dragging out one of its corners with the hand-shaped cursor (as is often possible with graphical objects in "direct manipulation" interfaces, but is not possible with the VPLab's objects.)

[104] Importantly, this comment was made before ER realized that he had a poor grasp of the meaning of the VPLab's main metaphor, i.e., that the Analysis workspace **basically simulates a monitor screen** on which video recordings of the experiment ('filmed' in the Manipulation workspace) can be replayed and that the images of such a recording are scaled down as on a real monitor.

[105] The simulated calculator does not have buttons. Instead, mathematical expressions are entered into it using the keyboard. It is rectangular but, contrary to most pocket calculators, its width is twice as long as its height.

One of the instruments, the tape measure, was most peculiar to ER. Though he had first hesitated, ER recognized that the virtual tape measure's shape was reminiscent of an actual tape measure. He thus expected its behavior, when handled, to be analogous to an actual tape measure's behavior; instead, when he used it, he felt that it behaved quite differently.[106]

Most importantly, he felt that the tape measure was "less real" because the measurement was read on its digital display and not on a tape with graduations. The digital display also seemed to create expectations for a very precise reading (more numbers after the decimal) ; at the same time, ER claimed that he was used to obtaining more precise values when measuring lengths. Furthermore, when assessing uncertainty of measurements made with the tape measure, ER hesitated because he felt that the tape measure combined seemingly opposite ways of producing measurements. In effect, dissonance occurred because, on the one hand, it was necessary to visually align the tape measure's components with the object that was being measured, and on the other hand, the reading of the measurement was obtained on a digital display within a computerized environment:

> *Well, it's because [the tape measure] is between… Because, given the fact that [the VPLab] is a computerized system, you tell yourself that it is going to measure precisely – direct, precise, real values. But this is rather somewhere between taking precise values and taking values that refer to something that would be collected manually. So because it's between the two, I'm having a bit of difficulty…* [citation 19]

Performing uncertainty assessment

Performing uncertainty assessment within the VPLab was not overly strange for ER, although he felt that working with a computer usually meant that one could avoid performing certain tasks (like uncertainty assessment) by using automatic functions. Still, ER deemed it was normal to assess uncertainty when working with the VPLab, given that he considered it an important skill to acquire. Let us also note that he perceived uncertainty assessment as problematic with the tape measure but not with the ruler or the protractor.

The VPLab's main metaphor (virtual camcorder and virtual monitor) / Use of a scale factor

Of chief interest is ER's poor understanding of the main metaphor and the verisimilitude judgments that concern it.

After having recorded a sequence of the disk's motion in the Manipulation workspace, ER expected to view the recording in a larger format, on the spot, by obtaining a blow up of the camcorder's small screen. Consequently, it is very interesting that he did not correctly identify this as the function served by the Analysis workspace's monitor when he got around to seeing it. Instead, he mistook the monitor for a "window" allowing one to launch

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[106] First, he felt that the virtual tape measure behaved differently from a real one because, once the tape was deployed, he could make the casing rotate fluidly around the ring at the end of the tape (which was then stuck in place to be used as the first point of reference for the measurement). Second, he did not expect to use the red slider (on the side of the casing) to immobilize the ring and move the casing around it– instead, he felt that this type of slider usually has a different function on a real tape measure (that of locking the tape into place when its length was sufficient.)

the disk more accurately on the table or to tune parameters for launching the disk more accurately. It was only when the interviewer inadvertently gave ER a clue (by telling him to go back to the beginning of the 'filmed' sequence), that he started regarding this 'window' as something that could offer a 'playback' functionality. At this point, when asked to state what he thought the workspace monitor represented, ER hesitated for a long time, then said it could be a camera and finally surmised that it represented nothing that actually existed – the *Zoom* and *Trace* control panels were responsible for this conclusion.

Measuring the 'filmed' image of the scale marker was no help in stabilizing the metaphor. Though he postulated that the marker represented some kind of scale, ER could not understand why it was not possible, with the ruler, to obtain a measurement of the scale marker's image equal to the "20 cm" that was written on it.

Later, during the debriefing (after the interviewer had explained the metaphor and the use of the scale), ER stated that doing scale conversions of measurements did not correspond to reality. His past experience seems to have been crucial in forming this judgment:

> ***ER:*** *[…]I was really expecting to measure [between] dots. In fact, it's because I was relating this to when I had done this in college – when I measured distances between dots [in college], I was not doing it through a window. I was measuring directly: the distance [measured] between two dots WAS the distance between two dots. I would not have expected to go to a [monitor]screen and to have to transpose [the measurement].*
>
> ***Interviewer****: And now that you know, does it seem strange to work like this ? Or is it normal…*
>
> ***ER****: Well… strange […] It bothers me.*
>
> ***Interviewer****: In reference to what you've done in the past, it still bothers you ?*
>
> ***ER****: Well, it bothers me to have to do scale conversions of measurements […] it's like calculating something that does not correspond to anything real.* [citation 57]

Tellingly, he also likened working with the Analysis workspace to playing a video game. More to the point, he made an interesting link between the Analysis workspace and a video game which has the player act as a pilot in a cockpit:

> *When I use these instruments, it doesn't relate to anything real. It's purely like playing a video game with a plane cockpit.* [citation 58]

Although ER did not elaborate on this, one can imagine how a simulated cockpit with instruments and dials laid out below a windshield could be perceived similarly to the VPLab's virtual monitor screen with measuring instruments laid out around it.

Traces appearing ahead of the object in motion (in playback)

Measuring distances between traces was something ER had previously done in a school lab. But because ER was relating to his experience of using a carbon paper tracing system for this type of experiment, it seemed strange and impossible that there should be traces ahead of the object (the disk) which was in motion (during playback). Hence, we believe here that traces 'moving along' *ahead* of the object in motion (in this case, the disk) is a cue that works against verisimilitude.

Verisimilitude of the disk's motion on the air-table

Much like AN, subject ER was able to discern between the simulation's model and its presentation: he noticed that the disk's motion was jerky when it was very slow but he proposed that this was due to poor visual presentation of the motion.

This being said, the subject felt that the disk's motion was not realistic, in other regards. ER did acknowledge the presence of friction working against the disk's motion when he observed that the disk slowed down after having been launched. However, he felt that it was not slowing down fast enough (note that ER had prior experience with a different type of air-table– see his **profile** in Appendix A). He believed that air friction had been included in the simulation, but that residual friction *due to the table's surface itself* had not been. To ER, this made things out to be somewhat "less real".

Expectations of ideal conditions / Impossibility of detecting degraded experimental conditions

ER *believed* that the air-table's sides (on which the disk had rebounded) were perfectly uniform and that it would be impossible to replicate them in an actual lab. In a related matter, ER expected that physical factors (a gust of wind blowing on the disk, for example) which could cause experimental results to stray dramatically from theoretical predictions, would be absent [107] from the VPLab. When later told that 'physical anomalies' might in fact have been simulated, ER said he would not have expected them to exist nor would he expect to be able to detect their presence:

> *It's a computer, [so] everything goes well: there would be no physiological problems in the apparatus. And also, when you experiment [in an actual lab], you do it yourself – you see… you'll know if a piece of dirt [on the table] has deviated the projectile… but in this case [i.e., with the VPLab], I don't know if you can physiologically perceive the anomalies. Anyway, it's good that these types of errors exist [in the VPLab].* [citation 6]

C.1.2 Subjects FS, GT, HU, IV: mechanical engineering students

Subject FS

Evaluation of the VPLab's potential to allow performing educational experiments

During the debriefing interview, FS was asked to rate the VPLab's potential to allow performing educational experiments. He rated it between 4 and 5 on a 5 point scale (with 1 signifying 'a very low potential' and 5 signifying 'a very high potential'). The disk's motion (pointing to underlying constraints) and similarity to the video clip seemed to favor such a high rating. More on these topics, below.

The video clip

The video clip (comprised in the multimedia presentation of the simulation) was an important element of reference when FS made verisimilitude judgments concerning

[107] Rather than the term 'absent', ER used the word 'impossible'.

elements of the simulation (e.g., the disk's motion and the scale of the simulation itself.) Although the subject did not mention this explicitly, the fact that the simulation was depicted using the same point of view (bird's eye view) as the video clip is a factor which probably facilitated comparison between the clip and the simulation (when assessing the simulation's scale, for example).

The disk's motion (deceleration pointing to inclusion of residual friction)

Before the subject launched the disk on the air-table for the first time, he did not expect that it would stop on its own because he believed that friction had not been included at all in the simulation [108] (his reasons are described in the next section). When FS realized that the disk was slowing down, this became a major cue for verisimilitude because it signaled that real-world constraints had been included in the simulation:

> ***Interviewer****: Why does [the VPLab] have much potential [to allow performing physics experiments] ?*
>
> ***FS****: Well, when you watch the video clip and you watch this [simulation], both do exactly the same thing – [the simulation's designers] have included friction; they have included most of the constraints that could be applied to it.* [citation 59]

Perceived lack of visual fidelity: the simulation's 'game-like' graphical attributes / Perceived target users

It is the workspaces' graphical attributes – qualified by FS as "attractive" and "game-like"– that caused him to expect that residual friction would not be included at all in the simulation. Since the graphics were attractive to him, he felt that the VPLab was intended for high-school (or first year college) students, because attractive graphics would help muster beginners' interest. Furthermore, to his mind, students at this level were often told by their teachers to neglect some aspects of the phenomenon involved in the experiment (air friction, for example), in order to simplify analysis; FS probably associated the act of neglecting residual friction *at the time of analysis* with the act of neglecting residual friction *when designing the simulation itself*. In any case, FS's judgment starts with perception of graphical attributes (attractive), which probably lead him to imagine appropriate target users (beginners), and then to anticipate the simulation's level of complexity (simple).

For the same reasons, FS also seemed to feel less involved in some tasks like uncertainty assessment:

> ***FS****: Well I was still thinking that I would do [uncertainty assessment] approximately.*
>
> ***Interviewer****: Is it still because [the VPLab] doesn't seem serious enough to you ?*
>
> ***FS****: Well, it looks like a game… that's why. You do it quickly…* [citation 60]

Visual fidelity (or lack thereof) still seemed to matter for this subject, even though verisimilitude of the simulation had been enhanced by the realization that the simulated

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[108] This is rather surprising given the fact that FS had already consulted the multimedia Presentation document which begins by stating that the user "will have the possibility to observe and analyze an object's motion on a surface with very little friction" It had thus been possible (if one paid sufficient attention while reading) to infer that the mention of *very little* friction entailed the inclusion of *some* friction in the simulation.

disk's motion was more complex than he had first thought. During the debriefing interview, the subject proposed that photo-realistic images – including elements such as "**a nicer texture**" , as well as **instruments** and **colors** that "look more real" – may help provide "a greater impression that [the environment] is real".[109] A greater sense of presence seemed to be at stake here:

> *Of course, the nearer it gets to reality, the more you will feel part of that world. You'll forget your surroundings and you'll really concentrate on [the simulation].* [citation 61]

This may be an attitude which can be cultivated through more extensive use of 'realistic' or visually appealing video games (FS reported that he often played video games).[110]

'Direct' manipulation / Affordance of errors on measurements (uncertainty assessment)

During the session, FS seemed to believe that it was normal to launch the disk on the table by manipulating it with the mouse and cursor (rather than through other input devices and modes of control). He made comments which would indicate that he approved of the level of precision that was thus afforded. Later, at the beginning of the debriefing interview, FS was asked what he thought of the VPLab, in general. One of the first things he mentioned was that he appreciated 'directly' manipulating objects:

> *It's not just entering data and getting answers in return. You actually manipulate things.*
>
> *There is uncertainty involved and it really emphasizes that there is a stake in error [on measurements].* [citation 62]

We also see from this excerpt, that the affordance of error in measurements (and thus, of uncertainty assessment) is an important feature.[111] FS's initial reaction, when he first began to measure distances with the tape measure, was different however. Having made prior use of Computer Assisted Design software, he felt that the VPLab's instruments did not offer the same level of precision and convenience as the tools in such packages; for example, he would have liked to "snap" (automatically fix) the tape measure onto the extremity of the object he was measuring.

As he made further use of the tape measure, his attitude towards it seemed to change: he said he enjoyed using it because it was fun and it gave him a measurement that was "approximate, *yet still precise.*" [citation 63]

It is also extremely important to note that FS was considering uncertainty assessment in reference to the context of simulating an actual lab and that it made sense to him within this context:

> ***Interviewer:*** *Is it normal or strange to ask you to assess uncertainty here ?*
>
> ***FS:*** *No, no… That's always fine: no instrument can be 100% reliable. And furthermore, with this software, you realize that the purpose is to simulate something [so] you have some error [uncertainty].* [citation 64]

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[109] We must note that this subject praised the VPLab for its "attractive" graphics (probably in comparison to 'home-made' software) and said that these would help foster interest in working with the environment.

[110] On the other hand, subject CP also reported playing video games "often" and he hardly mentioned the graphics except to say that they were stimulating. Moreover, subject ER reported that he "almost never played" video games but he criticized the VPLab's graphical quality, anyway.

[111] Note that requiring FS to evaluate uncertainty and discussing this topic during the session might have helped to elicit this comment.

The VPLab's main metaphor (virtual camcorder and virtual monitor) / The Trace function

More than any other subject, FS seemed to interpret the VPLab's main metaphor in a very 'literal' way (Smith, 1987). For instance, he was one of very few subjects to explicitly consider whether the virtual camcorder was placed inside or outside the merry-go-round [112] (before he used it to record the disk while working in the Manipulation workspace).

Moreover, his description of the meaning of the Analysis worskpace's main display was exactly that which the VPLab's designers had intended to convey:

> ***Interviewer****: What does this [work]space represent ?*
>
> ***FS****: Well it's as if the camcorder was connected to a flat video screen placed on the ground [facing upwards]. You would have your instruments there and you could work on the screen. […] It looks like a smooth screen– if this were in reality, you could put the objects [i.e., instruments] on it.* [citation 65]

Three elements mainly contributed to ascribing this meaning to the display. The first cue was measuring the 'filmed' image of the scale marker with the ruler and obtaining a measurement inferior to the "20 cm" which was written on it. This established a scale correspondence [113] to the Manipulation workspace simulation and it may have also conferred a different reality status to the Analysis workspace.

The second element contributing to a literal interpretation of the metaphor was the possibility of zooming in and out of the recorded image displayed in the Analysis workspace– a strong cue leading to comprehension of the metaphor thus emerged: namely, the fact that instruments and panels outside the playback area (outside the virtual monitor's frame) remained in place and kept the same scale after zooming in and out (hence only the image inside the screen's frame varied in size).

The third element was the different textures used for the frame of the virtual monitor and for the screen itself. While the frame's embossed texture reminded FS of a metal floor, the center part of the display seemed flat (and transparent) as a smooth screen.

FS is one of two subjects that likened the yellow *Traces* (displayed in the Analysis workspace) to the display of special effects 'traces' that follow a hockey puck in real-time during the broadcast of hockey games on an American television network.[114] This case is very interesting for three reasons. First, it is an example of a subject using a referent radically different from that which most subjects used (and closer to the designers' own referent) – this must be somewhat related to FS's understanding of the main metaphor (see above).

Second, it is a case where various elements are combined to produce specific meaning: an actual television screen **vs.** the VPLab's virtual monitor + the hockey puck **vs**. the disk in the simulated experiment + the VPLab's yellow *Traces* **vs.** the traces produced by special

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[112] This is a crucial question in the context of an experiment concerned with rotating frames of reference because motion seen from outside the frame of reference will not be the same as motion seen from within.

[113] Contrary to some subjects, FS was not in the least bothered by having to do scale conversions of measurements.

[114] He referred to a television program called "NHL (National Hockey League) on FOX".

effects on television. In effect, had the simulated experiment involved something other than a **disk,** say a pendulum for instance, perhaps the subject would not have made this connection with a hockey broadcast's special effects which involved another type of **disk**: a hockey puck.

Third, it is a case where knowledge of other media is mobilized when considering features of a software environment. Technical knowledge of such media may be used when making verisimilitude judgments. Even though FS believed that the *Traces* would be very hard to reproduce in an actual lab, he did not completely exclude that possibility: he claimed that it would be necessary to use a video editing consol in order to superimpose video images of the disk corresponding to different time indexes in the recording.

Physical feeling (presence) / Ontological status of the VPLab

We have already stated that FS gave the VPLab a very high score (4.5 on a 5-point scale) for its potential in allowing to perform physics experiments. When he was asked why he had not given it a perfect score (5 on 5), FS answered that there is a loss of physical feeling associated with working on a computer and that it was still possible to doubt simulations in cases where a simulated object's motion would seem very strange. "Everybody is a bit like Saint-Thomas," he claimed, "you'd like to get into the machine and really launch [the disk] yourself." [citation 66].

When asked if working in an immersive virtual environment would solve this problem, he answered that it would still not be the same as being in an actual lab since one would not feel things like centrifugal force acting on one's body while standing inside the merry-go-round; he added that, by working with a simulation, one loses the "sense of danger" that one experiences while doing chemistry or physics experiments in an actual lab.

Results that stray radically from theoretical predictions

During debriefing, FS stated that if a simulated experiment's results strayed radically from theoretical predictions, he would be tempted to blame the simulation for being inaccurate (after having excluded error on the part of the experimenter as a probable cause).

Subject GT

The video clip and the multimedia explanations (in the Presentation workspace)

The video clip and multimedia explanations in the Presentation workspace were used by this subject as a basis for verisimilitude judgments concerning the disk's movement and the scale of objects represented by the simulation:

> ***Interviewer:*** *What's going on ?*
>
> ***GT:*** *Well, when [the disk] hits one side of the table, it keeps going so I imagine – like I saw in the film [i.e., the video clip] – that [the side of the table] is like an elastic that perpetuates the motion.*
>
> *[…]*
>
> ***Interviewer:*** *So why was the 20cm marker put there [in the simulation] ?*
>
> ***GT:*** *In my opinion, it's to give the scale of reality.*

Interviewer: *And where is reality ?*

GT: *Reality is what we saw in the film – the merry-go-round. […] In comparison to the film, we see that it is realistic and that 15 people can sit on the bench [in the merry-go-round], so the size [i.e., the scale] seems realistic to me.* [citation 67]

Verisimilitude of the disk's motion on the air-table / Complexity of the simulation: ideal conditions (physical flaws not included in simulation)

There were two dimensions to GT's judgments concerning the disk's motion. Judgments of one kind were exhibited during the session, when GT stated that the disk's motion was "quite realistic". Cues used for this judgment included angles of collisions between the disk and the sides of the table being similar to those on a billiards table (angle after collision is "opposite" to angle before collision); rotation of the disk about its own center; rapid cessation of motion when the pump is inactive; and slow deceleration of the disk after having been launched (when the pump is active). Note that GT attributed this deceleration to a "loss of energy" (for which he did not specify a cause), but he also made comments which would indicate he was not aware of the existence of residual friction working against the disk's motion.

Interestingly, during the debriefing interview, GT displayed judgments which integrated another dimension of verisimilitude: that of *constructedness* (i.e., alteration through mediation of the phenomenon). He claimed that if he were to launch the disk on the actual air-table depicted in the video clip, the actual disk's motion would not be exactly the same as the simulated one:

[…] the object [the disk] may not move at the same speed or… I really have to tell you that it will never be the same; the object will never move like the real one even if it starts at the same position [and you launch it] with the same force. Given that the computer does not account for everything that happens in reality, I would not obtain the same [experimental] results at the end. It may be close, though. ***But*** *you will never have [exactly] the same results. So you would have three types of results: the theoretical result [i.e., prediction] shared by all, the result obtained with [the VPLab] and the result that you really would get in reality.* [citation 68]

What's even more interesting about this comment is that it was made not long after GT had been told that anomalies and 'physical' sources of error might have been included in the simulation.[115]

It is highly significant that **before he was told this**, GT believed even more deeply that conditions within a simulation were ideal. First evidence of this was found in his statement to the effect that it is good to include possibilities of error in measurements when "simulating a *real* experiment" **–** absent that, he said, "experimental results would be *practically* the same as theoretical results [i.e., predictions]." [citation 69] Another comment made by GT demonstrates this attitude even more convincingly:

A computer is perfect […] When you activate the air-cushion pump, it's precise. The pump produces constant pressure. So this is data that will be more precise on a computer than in reality. The computer does not account for all, all, all of what is in reality so it's certain that your results will be almost perfect compared to reality. [citation 70]

This part of the discussion followed a thread in which GT recalled a statics experiment that all engineering subjects had previously done at their university. In that particular

[115] In our view, this may either be a manifestation of awareness of differences between a model and reality, or else of more basic mistrust of simulation.

experiment, as GT recalled, outcomes had not been predicted – and, to GT's mind, could never have been predicted – by the equations which students had been using because these equations included factors presumed to be 'ideal', but which were not in reality. "So we say that experimental reality cannot get close to theoretical simulation," he concluded. [citation 71] From this, he then inferred that if the statics experiment in question were to be simulated on the VPLab, its outcome would be "perfect" (given the extreme precision of instruments which had been used in the actual lab), its results conforming not to reality itself but instead to equations based on presumption of an 'ideal' experimental set-up. [116]

Precision and possibilities when manipulating the disk

GT gave further justifications for his belief that actual experimental results would differ from those obtained with the VPLab's simulation of the air-table and merry-go-round. He claimed that in a real lab, one could know what force had been applied when launching the disk with the elastics which lined the table's sides. This is something that he had not been able to do in the VPLab (he would not exclude that possibility, however). He also seemed to say that the initial position of the disk before its launch would not be as precise in the VPLab's simulation as in an actual lab.

In another area of interest, after having tried three times to launch the disk as fast as he could during the session, GT commented that he would be able to launch the disk faster in an actual lab.

Instruments which look like they can be grabbed with one's hands (like objects depicted in video games) / Manipulation of instruments via a mouse and cursor

While exploring the Manipulation workspace, GT declared that it looked like a video game. When asked why, he answered that it had to do with the type of instruments available as well as the way they looked and the way they were controlled. For GT, "looking like a video game" had the connotation of "being very realistic":

> *In video games, we often see this – a logbook or a camera. [The VPLab's camcorder] is designed in a very real… very realistic way: you can almost manipulate it… with your fingers. You click on a button with the finger [i.e., cursor] and it closes [the camcorder's screen] automatically. So it's very realistic, it's gadgety […] You don't enter functions with the keyboard – it's almost always done with the mouse and a hand [i.e., cursor] on the screen.* [citation 15]

As we shall see below, this turned out to be a source of dissonance for GT.

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[116] An informant (the professor who had taught the class which featured this experiment) told us that the discrepancies obtained by the students, between theory and experimental results, were due to errors in the experimental set-up. However, our informant added that these errors could themselves be simulated without too much effort. This is crucial because GT might not have been fully aware of this fact or what it entails when considering possible simulation of this statics experiment: namely, that more constraints could eventually be fed into a computer model, allowing a simulation to get very close to experimental reality. Admittedly, extrapolating from GT's comment, one may suppose that had a simulation been used, some of the statics experiment's objectives might not have been attained by certain students– the hindrance would have been students' unfavorable attitudes towards simulation or a basic ontological limitation: students would have been comparing a more simplified model of reality (theoretical equations) to a less simplified model of reality (a sophisticated computer model with additional complexities), but not to experimental reality itself.

The main metaphor / Impossibility of "snapping" instruments onto graphical objects being measured

GT's poor grasp of the main metaphor and special expectations as to how tools should behave is essential to our understanding of his judgments. We examine his reactions to the VPLab's relevant features:

1 - Before he saw a demonstration of how to work with the VPLab
2 - After he saw a demonstration of how to work with the VPLab

– Before seeing a demonstration of how to work with the VPLab

After having recorded a sequence of images in the Manipulation workspace, GT predicted that he would be able to analyze and obtain measurements from the recordings by going to the Analysis workspace. He felt that this separation of tasks, between the Manipulation and Analysis workspaces, was satisfactory given the constraint of having to work on a computer:

> *This is good. It's a lot like real results. I think it's a good way [to do things] on a computer because in reality you don't need to record since you're there, you see, you handle [apparatus], and you collect your results at that time.* [citation 72]

While he worked in the Analysis workspace, however, GT said he "did not know how the ruler worked" [citation 73]. He kept trying to find a way of selecting an object in the virtual monitor's recorded image, as if the system could recognize and isolate objects in the image, in order to measure them with the ruler (but the ruler was designed to be used by simply taking a visual reading with the help of graduations [117]). This way of isolating and working on graphical objects is widely used within the kinds of design software and CAD packages with which GT was familiar. He thus had a very hard time understanding why it was impossible to connect the tape measure with the object being measured (i.e., to 'snap' the tape measure's ring onto a point of the recorded image).

A bit later, he figured out that the tape measure's digital display indicated 0mm only when there was a specific alignment of the tape measure's ring with a red reference mark on the tape measure's casing. This must have cued him to the fact that he could "visually" assess lengths by using the tape measure, but tellingly he qualified this – the intended method for measuring lengths with the tape measure – "an approximation".

At that point, he might have become aware of the scale conversions necessary when measuring lengths of objects in the recorded images; this, along with the impossibility of "touching objects" in the recording, probably caused him to have a better grasp of the main metaphor (i.e., that the virtual camcorder, in the Analysis Workspace, is connected to a virtual monitor which only represents a display device). He thus perceived that he could "visually compare" an image's size to the ruler's graduations. However, he immediately stipulated that this way of visually assessing lengths *lacked precision*.

Still, he looked for a more precise way of assessing lengths. He persisted in saying that he could not *measure* objects knowing only what he then knew. When pressed to measure the

[117] The difference in scale between the image of the 20cm scale marker and the ruler's graduations seemed to contribute to GT's confusion. At one point, he thought that the graduations had only been drawn on the tool to identify it as a ruler.

recorded image of the scale marker with the ruler, GT answered that it was not necessary since ‘20cm’ was already written on the scale marker. [118]

To sum up, *the act of measuring* implied great precision for GT – precision and methods available with software tools he had frequently used, and precision which had been required of him in the course of his past employment as a parts inspector in the field of aeronautics. Hence, GT was not poised to fully understand the metaphor (or to understand how measurements could be accomplished). [119]

– After seeing a demonstration of how to work with the VPLab

At the beginning of the debriefing discussion, the interviewer felt it was appropriate to demonstrate how one could work with the VPLab. [120] Following this demonstration, GT made further comments on the Analysis workspace’s monitor. He explained that it was extremely unnatural for him to measure things directly on a screen, because in a professional context this was seen as lacking precision; he also explained that his point of view was now changing because he had more consideration for the intended use of the VPLab:

> *It’s like when you look at a design drawing, working for a firm. They tell you not to measure on the drawing even if it is scaled – no ! – really because this lacks precision. But here we’re talking about a physical experiment.[121] That’s why my point of view is changing a bit because I’ve been thinking too much in terms of components production…* [citation 74]

GT also stated that measuring distances on a video recording would be more complicated in an actual lab. He said that if he were to really film this experiment in a lab, he would fix a grid onto the table’s surface in order to locate the disk precisely during playback. Although he did not say so explicitly, the virtual monitor’s ***Trace*** function seemed to be the key element which for him, differentiated the VPLab’s analysis functionalities from actual video analysis:

> *[…] because in reality, I would have trouble measuring distances between instant 1 and instant 2 [i.e., at different time indexes]. I would almost have to stop the camera – pause the camera – and determine a path on the television screen, and then roughly assess its length.* [citation 75]

As for the monitor’s ***Zoom*** function**,** it was seen as allowing for precision of measurement, which in turn made the VPLab more credible. The remaining uncertainty seemed more acceptable to GT, *especially given the context of trying to simulate experimental work in physics*.

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[118] GT had not yet realized that the letters “cm” were written on the ruler.

[119] In other terms, this subject expected more ‘magical features’ (Smith, 1987) than were available in the interface. GT was thus also unable to predict how one would measure the velocity of the disk because he could not figure out how to assess time intervals between traces. He never realized that he could have used the virtual monitor’s time display, and he looked instead for more ‘instantaneous’ ways of obtaining time intervals. He was also unable to assess uncertainty of measurement. The ensuing confusion and frustration may have caused GT to express negative judgments concerning the VPLab. The session was stopped short.

[120] The subject said that this demonstration had “opened his eyes”. Discourse and assistance should eventually be seen as cues for verisimilitude when real users actually interact with the VPLab in a pedagogical context. It was not our goal to highlight these but our study may serve to recommend what type of ‘discursive’ cues should be made available to students in order to complement ‘non-discursive’ cues.

[121] “Physical experiment” is translated from “expérience physique” in French. There is a possibility that the subject might have actually meant “a physics experiment”.

Impossibility of manipulating instruments with one's hands / Lack of precision when measuring (because of visual alignment)

Even if the *Zoom* function improved upon the accuracy of measurements, GT still had a more basic grievance with the interface. At the beginning of the session, he had said that the instruments were very realistic and that they looked like they could be grabbed with one's hands. During the debriefing, GT claimed that this property had, in part, been the cause of his problems with the main metaphor. Dissonance had occurred due to tension between how GT regarded the instruments' visual presentation and the type of manipulation that was possible:

> ***GT****: Us [engineers], we're used to plugging numbers into formulas– numbers with lots of decimals. It's also a very serious field, very conservative […] This is software which is attractive, it's gadgety […] but it's not the type of software we… we use things that are only technical and that's why I was disconcerted.*
>
> ***Interviewer****: OK. You weren't in your own world.*
>
> ***GT****: That's it ! Exactly. A drawing like this [protractor] interferes with my real world […] In my real world, I could take these instruments, play around with them on a table and use the ruler, in my own way, to perform measurements. However, in this case, I can't touch [the instruments] and 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.* [citation 18]

From this excerpt we also gather, notably, that visual alignment of instruments on objects being measured is problematic in the VPLab (and much less so in an actual lab).

Subject HU

When asked what he thought of the VPLab compared to the lab work he had done in the past, HU answered "Everything is there," from which we infer that, in his opinion, none of the important elements of an actual lab were missing. We wish to cite HU's case as an example of a student which had quite an unfavorable *a priori* attitude toward simulation but still seemed to find the VPLab credible, on the whole.

Evaluation of the VPLab's potential to allow performing experiments / The main metaphor

During the debriefing interview, HU evaluated the VPLab's potential to allow performing physics experiments, on a 5-point scale. The rating he gave was just below 4. He put forward two arguments for not giving a higher rating. The first had to do with his impression of having a better grasp of things in an actual lab.[122] His second argument was that **measuring was faster (or less fastidious) in an actual lab because you could measure distances directly** – he was comparing the process of measuring in the VPLab to the process of measuring distances between marks made by electrical discharges on carbon paper (when using a tracing system in an actual lab):

[122] This may have had something to do with feeling less *presence* in the VPLab. "Driving a real car and driving a car simulator do not provide the same feeling," said HU shortly after claiming that there was less precision when launching the disk in the VPLab than in an actual lab. [citation 76]

__HU__: I feel more at ease when taking measurements [in an actual lab] ; you can take the sheet [of carbon paper] and work directly on it without having to factor in a [scale] ratio.

***Interviewer**: It's having to factor in the scale ratio that…*

***HU**: Well, not necessarily. It's just faster [in an actual lab]… there's no zoom […] With [the VPLab], the concept is good except that you have to go through two or three steps in order to obtain one measurement.*

***Interviewer:** The manipulations themselves are more fastidious ?*

***HU**: Yes, a bit. Here, I measured three distances and it took me some time to do so, whereas, had I been in a lab, it could have taken me only one minute… On the other hand, it couldn't have been any faster [on a computer]. I don't see a way of making it faster [on a computer].* [citation 77]

There are too many steps in the process of measuring lengths and the *Zoom* function is seen as something which is unnecessary in an actual lab.[123] In our opinion, this is HU's chief negative judgment in regards to verisimilitude. Notice, though, that it seems acceptable enough to HU, given the constraint of having to work on a computer.

In an issue related to the virtual camcorder, HU did not consider that the available view of the air-table was very plausible . This is because he felt that the camcorder's perspective (that of rotating with the table) would be impossible to replicate in an actual student lab, if one were to rotate the table without using a merry-go-round.

Understanding the metaphor (use of a scale factor to establish a correspondence between workspaces)

During the session, HU interpreted the meaning of the main metaphor on his own, while exploring the Analysis workspace. One of the cues for this was measuring the 'filmed' image of the scale marker with the ruler and obtaining a measurement inferior to the "20 cm" which was written on it. This was not sufficient, however, because he still believed it possible to obtain a measurement equal to 20 cm by zooming in on the recorded image. At this point, he thought that he was viewing the recording *through the camcorder* instead of viewing it on a monitor**.** It was only after he had zoomed-in on the recorded image and still obtained a measurement inferior to 20 cm that he realized it was necessary to perform scale conversions of measurements made in the Analysis workspace. Thereafter, it is very likely that HU still thought that he was viewing and replaying the scene through the camcorder (and that he was using the zoom function of a camcorder, as opposed to that of a monitor) but at least, he had realized that he could not obtain full-scale images of the objects.

Moreover, HU's understanding of the metaphor was also promoted by his recollection of a documentary in which a camera had been used to analyze the motion of an object. When asked what features of the Analysis workspace reminded him of this situation, HU named two: the time display on the virtual camcorder (it is very similar, incidentally, to the monitor's time display) and the grid-like pattern formed by the tiles on the virtual merry-go-round's floor [124], which reminded him of the grid used to locate objects more accurately in a two-dimensional space. The use of this last cue is quite surprising, as the intended

[123] We take this to be a judgment of the main metaphor (virtual monitor).
[124] There were no tiles on the floor of the actual merry-go-round depicted in the video clip.

purpose of drawing tiles on the merry-go-round's floor was not at all to convey this impression.[125]

Zoom function and Trace function

Measuring distances between traces was something HU had previously done in a lab. However, when HU was asked, during the debriefing interview, to identify any actions he had performed within the VPLab which would be impossible to reproduce in an actual lab, he named three: zooming-in on objects and changing the interval between *Traces,* as well as their number. He added that this flexibility with the VPLab's *Traces* was a good thing (see below).

Freedom in choosing methods / Control over actions (assessment of uncertainty)

Before the session, the interviewer had shown HU pictures of some of the instruments and had asked him to predict how he would use them to accomplish specific tasks. In the course of one of these exercises, the subject said:

> *I always think that it's experimental so [the procedure] can't be computer-driven; we have to do things ourselves.* [citation 78]

For this subject, the most important element which contributed to the VPLab's verisimilitude was probably freedom to choose work methods. This is linked, in our opinion, to the degree of control that one has over actions. One example of this is the possibility of varying the number of *Traces* and the interval between them. Though the act itself of varying these parameters was seen as impossible (see above), the freedom to do so contributed to the overall verisimilitude of working with the VPLab since it empowered the subject to choose his own method:

> *I do everything, basically. See here: I determine the number of dots [i.e., traces] and the interval [between them] myself, as I want… 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.* [citation 24]

Another example of this is the freedom to do (or forgo doing) uncertainty assessment:

> ***Interviewer****: What do you think about assessing uncertainty with software, in an environment like this one ? Do you think it's normal ?*
>
> ***HU****: Yes, it's normal. What I like about this, is that it's the same as in a lab: it's nothing less, nothing more. In a lab, you can forgo assessing uncertainty, if you so desire – you're free – you can forget about it if you want. There is nothing to tell you: "Here, you have a column [in your notebook] to note uncertainty." [Instead:] "I give you a blank notebook and you do what you want with the columns. You write what you want at the top."* [citation 79].

Though the interviewer required the subject to assess uncertainty, **the absence** of constraints, *within the environment itself,* which could force the user to comply seems to have promoted verisimilitude.

Uncertainty of measurement / Adequate precision of instruments

[125] Instead, the designers chose to draw tiles because it was the simplest way to add texture to the merry-go-round's floor.

It is obvious that the affordance of uncertainty of measurement was important for this subject, in regards to verisimilitude– note the strong ties with the notion of *control over actions* discussed above:

> *[…] 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.* [citation 17]

Here, we must insist that HU made this statement *before the interviewer required him to assess uncertainty* so that this requirement had nothing to do with the present judgment. After he was required to do so, HU was asked if he thought it strange, given that he was working with software. HU said it was good that students assess uncertainty themselves, rather than having the computer do it automatically for them, because this was an important practice to develop when performing experiments. This tells us that requiring HU to assess uncertainty may have been a cue favoring verisimilitude, as well.

Although the affordance of uncertainty of measurement was seen as favorable by HU, the virtual instruments' verisimilitude was diminished when the subject perceived they lacked precision compared to their real-world counterparts. The following excerpt is an excellent illustration. During the debriefing interview, subject HU rated the probability of finding the VPLab's protractor in a physics lab at 2 on a scale of 1 to 5 (with '1' meaning a very low probability and '5' meaning a very high probability). He gave the following explanation for this rating:

> *The protractors that I've used before had a calibration that was [detailed] to the one-degree mark. We would really see the one-degree mark… so the level of precision [of those protractors] is a bit higher [than that of the VPLab's protractor]. So this one may not be precise enough. I would say "2" - a low probability […] because it's not precise enough for a physics lab.* [citation 17]

Precision was an important criterion for judging verisimilitude of diverse aspects of the VPLab.

Verisimilitude of the disk's motion on the air-table / Points of view

The fact that the disk slowed down after having been launched (while the pump was on) gave this subject an indication that there was residual friction at work against the disk's motion. This yielded greater verisimilitude– HU made the following comment spontaneously during an exploration-based task:

> *It's good because we see that the disk is somewhat slowing down. Because having absolutely no friction is impossible.* [citation 80]

Overall, while in the Manipulation workspace, HU perceived that the disk's trajectory was "normal". However, he said he had a hard time assessing the disk's motion and was basing his judgment on what he supposed the disk's behavior should be. He claimed the difficulty stemmed from the fact that the simulation did not also offer a view of the air-table from outside the merry-go-round (as did the video clip, though very briefly). Consequently, we can also extrapolate from this that the view available was not effective enough, in its own right.

Later in the Analysis workspace, HU examined the disk's motion by measuring distances between positions in the disk's trajectory which corresponded to different time indexes. During this exercise, there was one very interesting event: HU obtained a measurement which ran counter to his expectations. He then explained this seemingly anomalous result by saying it was normal to encounter it since he was involved in "practical" work.[126]

Complexity of the simulation (random fluctuations and 'anomalies')

During the debriefing interview, it was suggested to HU that 'anomalies' and random fluctuations might have been included in the simulation. Examples given were the table's surface being sticky, small random fluctuations of the merry-go-round's speed, and vibration of the merry-go-round's motor causing, in turn, the whole structure including the table, to vibrate (only the last two elements were really included in the simulation).

Concerning the sticky surface, HU claimed that it was unwarranted since the goal of the experiment was really to study and understand the disk's motion (read 'normal' motion), and not to be confronted to tricky situations. Furthermore, he felt that such a circumstance could exist in an actual lab but could be easily avoided if students sufficiently prepared for the experiment. Similarly, in the case of the merry-go-round's speed fluctuations, the subject said that the fluctuations should be made small enough to be neglected (which was actually the case) because dealing with them "isn't the goal of the experiment." Finally in regards to vibrations of the merry-go-round's structure, HU proposed that it should be simulated only if the designers of the actual merry-go-round had intended these vibrations to exist. He did not believe this to be the case however:

> *If it is intentional, it must be replicated because there's a reason [for it]… but my impression is that if they were to construct another merry-go-round and wanted to do away with the vibrations, they would manage it. However, I think it's good to produce a simulation which represents, as much as possible, what it's like to really do the experiment. If you look at real flight simulators, they include wind turbulence; [for] a race car simulator, it's the condition of tires and adherence to the road… it's good to account for as many things as possible.* [citation 81]

For this subject, credibility is rather linked to the replication of as many conditions *as are 'inescapable' or 'useful'* in reality. This is an important nuance.

In a related matter, HU was asked to describe rare events witnessed in a physics lab which could not take place within the VPLab. He gave an example (pertaining to another field of physics) of committing an error when connecting electrical circuits, which would then lead to burned resistances. "In a simulator," he supposed, "the same thing could happen maybe, but well… you do a RESET and you start over." [citation 82] Hence, this nicely addresses the topic of possible consequences when experimenters make mistakes (while handling apparatus, in HU's example) within a simulated environment– provided, of course, that it is even possible to make mistakes.

Subject IV

Measuring instruments

[126] During the debriefing interview HU stated that it was he, and not the simulation, who would be at fault if he were to obtain results which radically strayed from theoretical predictions after having conducted the whole virtual experiment (he also said that he was usually at fault when this happened in an actual lab). He claimed he would not expect the computer to make mistakes.

When asked what he thought of working with the VPLab compared to his prior lab work, IV said that working with the VPLab "reflected" and "was faithful to" experimentation done in a lab. The measuring instruments were an extremely important part of IV's assessment of the VPLab: "*I can measure and do the same steps* [as I would in an experimentation]," he said, referring to how measurements were accomplished within the VPLab. [citation 83]

IV's judgments towards the virtual instruments were very complex and often seemed contradictory. A basic element in his attitude towards virtual instruments was his feeling that these tools allowed him to obtain the same data as in an actual lab:

> *[…] 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.* [citation 14].

On the other hand, IV claimed that he could never use a real tape measure in an actual lab with as much precision as that which he had enjoyed when using the VPLab's tape measure; thus he said he would use a slide caliper, instead. However, he judged that the virtual tape measure was ideal in the context of the virtual lab and imagined that handling a 'virtual slide caliper' through mouse-driven actions would have been tedious and awkward.

Subject IV enjoyed using the virtual tape measure and said that its "way of functioning" was the same as for "a real tape measure". In contrast, he was dissatisfied with the way some of the virtual instruments were manipulated compared to the actual objects that they represented. This had to do with certain limitations: for instance, he complained that the virtual ruler and protractor did not allow for arbitrary rotations (but were restricted to 90-degree turns) – although, he acknowledged that it was still possible to "do the same job" despite this limitation. At one point, he even went so far as to say there was an advantage to knowing that the protractor was perfectly horizontal or vertical; still, he would have deemed it more 'realistic' and satisfactory, had he been able to smoothly spin these instruments just by 'dragging' a corner in a circular motion. Consequently, verisimilitude of the ruler and protractor was probably diminished because mouse-driven actions were not well mapped onto manual operations (those possibly performed with one's hands when manipulating an actual ruler or protractor).

Coming back to the tape measure, we have said that IV claimed he was allowed much more precision with the VPLab's tape measure than if he had used the object it was meant to represent in an actual lab: this is because IV felt that the position of the instrument's components could be fine-tuned with greater accuracy through mouse-driven actions in a 2D space, than with his own hands in an actual lab. Verisimilitude of the measuring process was lessened by this. (We suppose that this perception of excessive accuracy may have also been linked to the added precision provided by zoom-ins.) Still, IV stipulated that uncertainty, due to required adjustments of the cursor's position, was nonetheless present and that this made measuring more "realistic" than if users had been allowed to instantaneously "snap" instruments onto objects.[127]

[127] Initially, he had expected to "snap" instruments onto objects because of his prior use of CAD software packages which had included this feature.

Another tool – the (virtual) rod which was designed to be assembled to the virtual protractor in order to take readings – was judged unusable in an actual lab. This graphical object appeared to represent something like a string, rather than a rigid rod.

To sum up, IV's judgments toward the virtual instruments were multi-dimensional and this is well illustrated by those judgments which concern the virtual tape measure: at a basic level, the virtual tape measure provided the same type of data that IV expected to obtain in an actual lab; at another level, the virtual tape measure's basic way of functioning was seen as similar to its real-world counterpart (probably because mappings of mouse-driven actions to hand-driven actions were judged to be satisfactory: manipulating the same types of components seemed to produce the same types of effects); at yet another level, IV said he would never use the virtual tape measure's real-world counterpart in an actual lab because it could never be manipulated with as much precision as what was provided through mouse-driven actions in a 2D space; finally, some imprecision remained despite this 'excess in precision' and this preserved verisimilitude, to some extent.

The video clip / No automatic initiation of the disk's motion

The video clip was used by this subject as a basis for verisimilitude judgments concerning the simulated disk's movement:

> *I would expect that the faster [the merry-go-round] goes, the more [the disk] should move about, but that's not what they said in the video clip so it's normal that it doesn't do this.* [citation 84]

The video clip was also useful – combined with the fact that the disk's motion was not automatically initiated – when the subject apprehended his own role in the experiment:

> ***IV****:[…] when they introduced the simulation [in the video-clip], there was a man there [beside the air-table]. But now [in the simulation], nobody's there. So I imagine that if I'm the man, I have to be there and bring the disk […]*
>
> ***Interviewer****: Does it give you the impression that you are the man [in the video clip], or is it...*
>
> ***IV****: Well, I'm looking to do the experimentation, but as I saw in the video clip, it was the man who initiated the [disk's] motion. Because if I start the pump and do nothing else, nothing happens. However, if I start the pump and I give [the disk] a little push, it is going to start moving.* [citation 85]

Verisimilitude of the disk's motion on the air-table / Friction on the table

On the one hand, IV said that the disk's motion, in general, "did not seem strange to him, intuitively" (adding that he was not familiar with this type of motion and could not evaluate its dynamics, per se.) Additionally, IV thought that the disk reacted normally to changes in the merry-go-round's rotational speed: he observed that the motion of the disk changed when he augmented the merry-go-round's speed, and that it changed again when he stopped the merry-go-round completely– at this point, the disk took a while to come to a full stop, and this could be explained, IV believed, by "the principle of inertia". The subject thus felt confident that he could really gain knowledge about the disk's motion by performing the experiment.

On the other hand, IV felt it was strange, when the merry-go-round's speed was high, that the disk would sometimes become stuck in one corner of the air-table after having moved around a lot. "But maybe it is normal," he added, showing that he was not totally convinced either way. In fact, this behavior *was* realistic and likely to occur because the table was slightly off-center in the merry-go-round when IV made the observation; this, however, was overlooked by IV. We would like to point out that the 'strange' behavior in question was not shown in the video clip.

In a similar vein, (while the merry-go-round was not turning) IV observed that the disk decelerated after having been launched and he seemed to be uncertain as to whether correct behavior was being represented by the simulation– note that this uncertainty may have stemmed from the rate of deceleration of the disk:

> ***IV**: Uh… there's no friction– of course, there is always… [The disk] should always keep moving slightly. It should not stop that much or [it should only stop] after a very, very long time.*
>
> ***Interviewer**: Would you say that there is uncertainty as to the presence of friction ? Would you say that presently, you are not sure whether friction exists or not [on the table] ?*
>
> ***IV**: Yes… Well no, but I know that in real life, it is impossible to have [a surface] with absolutely no friction. It is logical that this [simulation] should account for that. But the uncertainty comes from me– by which I mean: what happens if there's friction and what happens if there isn't any? It's me and not the software.* [citation 86]

Let us note that the disk's deceleration finally became a cue pointing to non-zero friction, and thus favored verisimilitude:

> ***Interviewer**: If there wasn't any friction…*
>
> ***IV:** If there wasn't any, [the disk] would always keep moving slightly and it would continue the motion it was given.*
>
> ***Interviewer**: And, if there was friction [on the table] ?*
>
> ***IV**: Eventually, it would stop.*
>
> ***Interviewer**: What do you observe at this moment ?*
>
> ***IV**: I observe that [the simulation] is representing a situation where [the disk] really tends to stop eventually, so I think that there is a tiny bit of friction somewhere. To conclude, I think that reality is well represented by this.* [citation 86]

The VPLab's main metaphor (virtual camcorder, virtual monitor and the *Trace function*)

IV did not like the fact that the virtual camcorder had an upper limit in terms of recording duration. Although he acknowledged that this was "logical if one wanted to make a true simulation that represented reality," [citation 87] he was upset that this took away a potential advantage of a virtual lab over an actual one. Moreover, he felt that the allotted recording time (a few minutes) was much too short in comparison to actual camcorders– this, in fact, might have been the element that shocked IV. [128]

While he was exploring the Analysis workspace, IV was asked to describe what he thought the workspace's main display represented. We may observe that his interpretation of the metaphor was very close to what the VPLab's designers had intended to convey:

> *I have the impression of looking at… by analogy, it's as if I was looking at an oscilloscope and I could take measurements directly on the screen. […] It gives me the impression that I could be in front of a screen which, I hope, would be very flat […]* [citation 88]

Oscilloscopes – the actual instruments which, in IV's view, epitomize the VPLab's metaphor – are common in labs; hence, the metaphor seemed credible to this subject. Cues contributing to this interpretation included the following elements: the grid-like pattern

[128] This did not seem to be a problem for some of the other subjects (ER, FS and HU).

formed by the tiles on the virtual merry-go-round's floor (which, for IV, was indicative of a scale correspondence) ; the monitor's time display which was very similar to the virtual camcorder's time display; the colors (blues, violets and greens) used for the image displayed on the virtual monitor (instead of black and white) ; the blue screen which preceded the first image of each 'filmed' sequence (this made IV realize that the camcorder's small monitor and the main monitor were both displaying the same images).

Related to IV's interpretation of the metaphor, is his comparison of the yellow *Traces* displayed in the Analysis workspace, to the display of special effects 'traces' that follow a hockey puck during hockey game broadcasts (on an American television network).[129]

Complexity and ontological status of the simulation

During the debriefing interview, IV indicated that the VPLab would be appropriate if the purpose of an experiment was simply to observe a phenomenon as described by the laws of physics but inappropriate if the goal of an experiment was to confront 'real' behavior to behavior 'predicted by theory'. "*It isn't reality which is inside [the computer]*, IV said, *because that with which you feed the computer is the stuff of theory*." [130] [citation 89].

Importantly, this attitude towards simulation subsisted even after IV was told that anomalies might have been included in the VPLab's simulation: [131] although the mention of these anomalies reminded IV of trainees being confronted to problem-situations in flight simulators, it was not enough to significantly effect IV's attitude which consisted in dissociating simulation from the complexities of reality and associating it with 'pure' theory.

C.1.3 Subjects JW, KX, LY, MZ: physics students

Subject JW

Evaluation of the VPLab's potential to allow performing educational experiments

During the debriefing interview, subject JW rated the VPLab's potential to allow performing educational physics experiments. He rated it between 2 and 3 on a 5 point scale ('1' being a very low potential, and '5' a very high potential).

[129] Subject FS also made this comparison and, much like IV, his interpretation of the metaphor was extremely close to what designers had intended to convey.
[130] This was exactly the opinion expressed by subject GT. When making this argument, both GT and IV referred to the same *statics* experiment previously performed at their university.
[131] IV said that he would not have expected such anomalies to exist because a computer was supposed to be consistent and was not usually supposed to spontaneously generate errors. More importantly, in IV's opinion, the *usefulness* and *pertinence* of such anomalies were somewhat questionable in the context of the air-table experiment (when contrasted to the simulation of problem-situations in the context of skill training with a simulator).

Impossibility of manipulating objects with one's hands (tangibility) / Ontological status of the VPLab and visual fidelity

To explain such a relatively low rating, JW said that working with a mouse instead of manipulating apparatus and instruments with his own hands was a great disadvantage.[132] This was an issue which seemed to be merged with the question of the VPLab's ontological status (i.e., its status as a simulated environment) – we observed this when we asked JW to compare working with the VPLab, to working in an actual lab:

> ***JW:*** *[…] I think that there are some things, 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…*[citation 5]

Since there was a possibility that things seeming "*less real in the computer*" might be linked to visual fidelity, JW was asked if he thought that working within an immersive virtual environment would improve credibility:

> *[…] if it looked real, I think that people would believe it more– I would believe it more. But it's still a computer […] For example, if I were in a virtual reality where time dilation [a concept in the theory of relativity] would be demonstrated, maybe I would be more inclined to believe it in there [as opposed to with the VPLab], simply because it would have the sensation of being more real. At the same time, though, I could tell myself: "Yes, but this is a computer, so…"* [citation 90]

Based on this excerpt we believe that, in the case of subject JW, improving the VPLab's visual fidelity might slightly enhance verisimilitude but a basic lack of credibility would remain due to its ontological status (a visual simulation is a construction of computer-generated images). We must thus consider that this subject's unfavorable *a priori* attitude towards simulation is an important factor.

The VPLab's main metaphor (the Analysis workspace's virtual monitor and its Zoom and Trace functions)

JW felt that the Analysis workspace's background was representing something "like a television". Cues contributing to his interpretation of the metaphor included: the impossibility of manipulating the graphical objects which had previously been movable in the Manipulation workspace's simulation; the conventional representation of the virtual camcorder and the great similarities between the virtual camcorder's screen and the virtual monitor; the virtual monitor's frame; and last but certainly not least, the invariance of the ruler's dimensions and scale, before and after having zoomed-in on the displayed image.

During the debriefing interview, JW stated that replicating a device similar to the virtual monitor in an actual lab would be possible, but only if some sort of computer was involved. However, he felt that replicating the virtual monitor's *Zoom* and *Trace* functions would be a difficult endeavor.

[132] Referring to JW's profile in Appendix A, we see that manipulating apparatus with his own hands is, in his opinion, an essential part of laboratory work.

Verisimilitude of the disk's motion on the air-table (deceleration as a sign of residual friction)

The fact that the disk slowed down after having been launched gave this subject an indication that there was a loss of energy when the disk collided with the table's sides and that residual friction was working against the disk's motion. This yielded greater verisimilitude:

> *[…] it truly is like reality, for if the air-cushion was perfect – really ideal – then [the disk] would keep on going forever. This, however, gives you a taste of how things really happen.* [citation 91]

Optimal experimental conditions are expected because of the VPLab's nature

During the debriefing interview, JW said he'd expect that outcomes of an experiment with the VPLab would conform to theory, that behavior of simulated phenomena would be consistent from trial to trial and that experimental conditions would be optimal. This is because JW associated computers, in general, to 'perfection' and 'consistent' behavior. When told about the possible inclusion of anomalies and random fluctuations in simulated phenomena, JW said this would be good as it would show students that "sometimes things are not so pretty [in reality]". [citation 92]

Subject KX

Evaluation of the VPLab's potential to allow performing educational experiments

During the debriefing interview, KX evaluated the VPLab's potential for experimentation in a slightly different way, when considering different target users. He felt that the VPLab would be a very good substitute for students who did not have access to an actual lab, and hence gave it a rating of 5 (very high potential) on a 5 point scale.

On the other hand, he had a feeling that students would understand and learn more if they could do the experiment "concretely" in an actual lab. He thought that students with access to an actual lab should use it rather than the VPLab, especially since *it seemed possible to replicate most of its experiments in an actual lab*. In this context, KX's rating was just slightly lower (4 on the 5 point scale).

Less complexity compared to reality (impossibility of making errors, no randomness, and 'anomalies') / Experimental conditions that tend towards perfection

In order to justify this slightly lower rating (see just above), KX claimed that students would learn more in an actual lab because committing errors was less possible in the VPLab and nothing was left to chance:

> ***KX****: You can have errors in a lab, but here [in the VPLab] you have nothings– it's simulated: there is no source of randomness which comes into play. In a lab, you learn to be precise, but here all you have to do is… that is, unless errors of randomness appear [in the simulation].*
>
> ***Interviewer****: Is it possible, or is it plausible that these errors exist [in the VPLab] ?*
>
> ***KX:*** *Well, I don't know if they've been programmed.*
>
> ***Interviewer****: Is that something you would normally expect, or on contrary not at all ?*

KX: No, because later you have to find out why the randomness [i.e., the error] has occurred and that would be a bit complicated, as opposed to a lab where you can always say: "Yeah, I know, I launched [the disk] incorrectly… etc." […]

It's more complex [in an actual lab]. Here [in the VPLab], you have a limited number of variables which can come into play […] you can't simulate reality perfectly. So, I think that it would be much better in a lab.

[citation 93]

This subject is evidently judging the VPLab in terms of complexity compared to reality. We first conclude from this excerpt that KX would not normally expect the simulation's outcome to be probabilistic or to be affected by simulated 'anomalies'. Furthermore, if KX were to then realize that this was actually the case, it would become a major cue for verisimilitude. We have strong reasons to believe this because of what KX had to say when the interviewer did announce that 'anomalies' and random fluctuations could have been included in the simulation:

[…] if it is previously indicated that this is truly a model of a real situation, including those types of errors, then [such a simulation] would be very good in fact. [citation 94]

So we see that KX would want to be warned of the inclusion of random fluctuations and 'anomalies'. Due to his preconceived ideas toward simulation, he rather expected the VPLab to be an environment where *"conditions are perfectly controlled"* [citation 95].

Verisimilitude of the disk's motion on the air-table (deceleration as a sign of residual friction)

KX expected the disk to slowly decelerate after having been launched because of residual friction on the table (note that this stands somewhat in contrast to the above comments, regarding expectations of ideal conditions). Consequently, the fact that the disk actually did slow down after having been launched yielded greater verisimilitude.

Types of quantities measured and types of instruments available /

The types of entities that the subject was asked to measure or describe (time, distances, trajectories) promoted verisimilitude. From a general perspective, the types of instruments provided in the VPLab promoted verisimilitude, as KX felt that they allowed him to measure in ways similar to how measurements were performed an actual lab.

If we examine judgments toward specific instruments, however, it becomes apparent that some tools like the ruler promoted verisimilitude, whereas others – for instance, the tape measure – did not. Although he later admitted to using a tape measure in a lab, KX said that one would use a "laser", rather than a tape measure, to assess long distances.

Manipulation of the instruments (tape measure)

During the session, KX stated that it felt bizarre to handle the tape measure using a mouse, in a way that was *analogous to how he would control an actual tape measure with his hands* (the fact that he would need both hands to control a real tape measure seemed to contribute to this feeling of strangeness). He added that it did not feel strange to control the simulated ruler with the mouse.[133] He also felt that the tape measure behaved differently from a real one, as it was possible to make its ring (at the end of the tape) rotate fluidly around the casing.

Lack of precision when launching the disk on the air-table

Precision seemed to be an important criterion in KX's judgments. During the session, he was dissatisfied when he tried to launch the disk as fast he could. Then, very early in the debriefing interview, KX spontaneously complained about lack of precision when launching the disk– he would have wanted to determine the disk's velocity and direction with more accuracy. For this lack of precision, he blamed use of the mouse.

He said his request for greater precision was not based on the premise that there would in fact be more precision when launching a real disk on an actual air-table (though he did claim this). Instead, he justified his request by saying that the computer's potential was not being exploited enough:

> *That's just it: with a computer, theoretically you can enjoy much more precision than in a real experiment so it seems to me that [the VPLab] should take advantage of this a little.* [citation 96]

Precision of measurements / Uncertainty assessment

Precision was also a factor in regards to instruments used to perform measurements. On the one hand, KX felt that the virtual protractor lacked precision and he wished that more graduations had been included or that some other way had been found to make it as precise as an actual protractor.

On the other hand, he was the only subject who thought of evaluating uncertainty on length measurements without the interviewer having to suggest that he should do so. [134] Later, he stated that assessing uncertainty was normal insofar as uncertainty was a consequence of the width of the tape measure's ring (which was used as the reference point for the beginning of the measurement):

> ***Interviewer:*** *Does it seem either normal or strange that we should ask you to evaluate uncertainty in this case ? More or less normal ?*
>
> ***KX:*** *Uh… It's quite normal since the [tape measure's] ring makes it imprecise enough. Absent that, I would find it a bit strange given that with a computer you can [usually] obtain as much precision as you desire. Unless the context is such that one of the objectives of the lab report is to perform statistical analysis.* [citation 97]

We would like to point out that KX's verisimilitude judgment here also refers to a pedagogical objective (performing statistical analysis of errors) which he had identified as important even before seeing and interacting with the VPLab.

The VPLab's main metaphor (the Analysis workspace's virtual monitor and Trace function)

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[133] For subject KX, the fact that that the virtual ruler and protractor did not allow for arbitrary rotations (but were restricted to 90-degree turns) had a relatively small negative impact on verisimilitude, but worth mentioning nonetheless.

[134] In fact, his plan to assess uncertainty was prompted by the interviewer's request to measure distances as if he needed to produce a graph further on.

For KX, at first, the displayed image in the Analysis workspace did not seem to be like a recorded video sequence, as such. Then, when he was asked to interpret the Analysis workspace's main display, the subject felt that it was a video camera, and later he added that it was simply a "*board that presents results in an animated way*." [citation 98] Both interpretations were different from what the designers had intended to convey and less 'literal' than interpretations made by some of the other subjects.

In the Analysis workspace, KX used the ruler and tape to measure the 'filmed' image of a marker on which was written "20 cm". The fact that the measurement he obtained on the monitor was smaller than 20 cm established a scale correspondence to the Manipulation workspace simulation – the necessity of having to do scale conversions of measurements may have conferred a reality status to the Manipulation workspace different from that of the Analysis workspace:

> *I converted it using the scale – I converted it to real life centimeters.* [citation 99]

On another topic, KX deemed that it would be almost impossible to find an equivalent of the *Trace function* in an actual lab because he perceived it as being too versatile. This may have had a small negative effect on verisimilitude.[135]

Subject LY

Students communicating to compare results / Replicable experimental manipulations

During the debriefing interview, subject LY was asked what he thought of working with the VPLab compared to prior lab work. To his mind, the two were about equivalent, except that when working with the VPLab, he could not enjoy the experience of performing the same lab experiment with other students and communicating with them. LY felt that having the opportunity of comparing with other students' experimental set-ups and results was important. He wished that a repository of other students' results could be made available to VPLab users. In his opinion, a *sine qua non* condition for such a feature's usefulness would be that all students follow protocols which describe replicable experimental manipulations; he felt that the main action he had performed during the session – launching the disk on the air cushion table by dragging it with the hand-shaped cursor and releasing it – had been rather arbitrary (as opposed to replicable).

Evaluation of the VPLab's potential to allow performing educational experiments / Intuitiveness in handling of instruments

During the debriefing, LY rated the VPLab's potential to allow performing educational physics experiments:

> *I think it has good potential. Small improvements could be made – I could easily give it 3 or 4, say 3.5 [on a 5-point scale, with 1 signifying a very low potential and 5 signifying a very high potential].* [citation 100]

[135] The trace's width was perceived by KX as a source of uncertainty of measurement; this could have ultimately favored verisimilitude.

When asked why he hadn't given the VPLab a higher rating, LY answered that some instruments – like the virtual tape measure – should be as intuitive to use as their real counterparts:

> *Obvious things should be given. Things that you have to learn [in an actual lab] should be learned [in the virtual lab], but you shouldn't have to learn to measure with a tape measure.* [136] [citation 101]

Later however, LY stated that once he had learned how the tape measure was handled, the tool could do the job as it should be done and it could be used very much like an actual tape measure.

We must add that LY's basic faith in a simulated lab's potential to allow performing experiments was probably linked to his favorable *a priori* attitude towards the use of simulation in an educational context.[137] Tellingly, he claimed that training with a simulated lab was acceptable, given that the US Marines had used a special version of a desktop video game called DOOM for mission training.

Basic doubt as to deviation from a valid theoretical model / Theoretical (and mathematical) justification of the simulation's behavior

To further explain why he hadn't given the VPLab a higher rating, LY suggested that there was a basic risk to using this type of software in that a simulation might be based on an invalid theoretical model. He thus spontaneously brought up a fundamental credibility question; we should note however that he addressed it very idiosyncratically, in relation to his own tendency to scrutinize what teachers were exposing. LY asks a crucial question here: If students should always start by being skeptical of what teachers expose, then why should they blindly trust instructional simulations at face value ?

> ***LY**: […] you'll always have limitations: is this really representative of the theoretical model ? What's behind this [simulation] to make [the disk] move like that ? Did [the programmer] take a formula and simplify it to allow for nice motion ? […] That's what bothers me: you have this software but you can have it do anything you want. […]*
>
> *Of course, you tell yourself that they are teaching a class so they won't hand you any old thing. That not withstanding though, 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 saying nonsense. With [the VPLab], you can't really question things because there's an [intrinsic] limit in using the program itself: if you start to question things at home like that, you lose the whole purpose of using the software.*
>
> *You don't know 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 x happens, [the disk] automatically goes the other way... Or does it really work with a formula, with all values truly changing according to reality ? […]*
>
> ***Interviewer**: So it's really a question of credibility in what the simulation can produce compared to…*

[136] LY had not been able to find the tape measure's reference points for the beginning and the end of the measurement.

[137] Let us note that LY claimed he could not give the VPLab a rating of 5 (very high potential) because its users would not directly be in contact with the apparatus and instruments. This concerns the question of tangibility or presence.

> ***LY:*** *Yes, a question of credibility and [of knowing that] the principles are clear – that things aren't too hidden.*
>
> ***Interviewer****: So more disclosure is needed ?*
>
> ***LY:*** *Yes.* [citation 1]

We believe that in LY's case, a very important cue favoring verisimilitude would be extensive mathematical and theoretical information accompanying the simulation. The interviewer tested this assumption by showing LY theoretical explanations (in the *Explanations* workspace) which contained animations of the disk's motion (including vectors). LY stated that this type of information would promote credibility of the simulation. We believe that LY's expectations in regards to mathematical and theoretical descriptions of the simulation's behavior were conditioned by his prior experience with simulations created with MAPLE software: it seems that these visual simulations had been accompanied by real-time exposition of the formulas and calculations needed to render them.[138]

Graphical attributes / Distinction between the simulation's visual presentation and its underlying model

From what we have said above, it is obvious that LY had the capacity of discerning the simulation's underlying model from its visual presentation.

During the session, the subject stated that he expected a relatively high level of complexity from the simulation's model. LY was then told that other subjects (c.f. subject FS), upon seeing the graphical interface, had expected less complexity from the simulation's behavior because the graphical interface reminded them of a video game. When asked if he felt the same, LY answered that there "wasn't really a relation between content" and graphical quality. [citation 11]

What's more, after having been asked if he had previously played realistic video games, the subject made the following statement:

> *[The VPLab] is somewhat like SimCity [the videogame]* ***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.*
> [citation 12]

This excerpt also indicates that the simulation's complexity was sufficient in LY's opinion.[139] However, we shall see in the next section that his judgments in this area were not always so favorable.

Complexity of the simulation (the disk's motion, anomalies, errors in handling apparatus) / Multimedia explanations in the Presentation workspace

The fact that the disk slowed down after having been launched (while the pump was on) gave this subject an indication that there was residual friction at work against the disk's motion. This yielded greater verisimilitude.

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[138] This suggests that disclosing information concerning simulation modeling methods could enhance credibility (to the extent, of course, that the modeling methods are perceived as valid).

[139] Note that LY made this statement after he was shown the *Explanation* workspace containing theoretical demonstrations of the disk's behavior.

Conversely, when LY launched the disk straight towards the table's side (at a 90 degree angle), he observed that it traveled back and forth on the table's surface without deviating from a straight path. This indicated to LY that he could launch the disk at a perfect 90 degree angle (to the table's side), and that the table's surface and sides "were perfect". This seemed to work against verisimilitude: the subject claimed that "the conditions were perfect" and that the disk would "totally react [according] to theory" [citation 102].

LY did not seem to be bothered by the fact that one of the elements mentioned above (presence of residual friction on the table's floor) pointed to greater complexity of the simulation, while the other (the table's 'perfect' sides) pointed to lesser complexity. This was because the explanations in the Presentation workspace made things coherent for him: LY had noticed that '*minimized friction* on the table's surface' was mentioned in the Presentation document whereas no reference had been made in regards to the table's sides (thus, designers had no obligation of making the table's sides 'imperfect'). Moreover, LY believed that the users should be informed of any physical factors which had not been included in the simulation's model:

> *I expect that [the simulation] would take into account all physical factors involved – when you do an experiment, you take all physical factors into account, except if it is specified from the start that [including a given factor] would exceed the experiment's objectives [i.e., that it would not be useful to attain its objectives…] This is just being honest with the student […] if you tell him, he understands that something which goes on [in reality] is not represented [by the simulation] because it exceeds the course's content, or something like that…* [citation 103]

At any rate, the multimedia presentation of the experiment seemed to set the tone for LY's expectations of complexity and this was linked to his prior experiences in situations where teachers had announced, before specific experiments, that certain aspects of the physical phenomenon under study would not be taken into account. LY probably associated the act of neglecting these aspects *at the time of analysis* (in order to simplify the process), with the act of neglecting these aspects *when designing the simulation itself.*

When it was suggested during the debriefing interview that 'anomalies' and random fluctuations might have been included in the simulation's model, the subject reacted by saying that this would improve the simulation and raise it to another level, but he also recommended that students be warned of these factors because they would not expect them.

Later, when he was asked to name any events which could take place or actions which could be accomplished in an actual lab but not within the VPLab, LY mentioned that handling errors which would ruin the experiment (e.g., making a wrong electrical connection in another type of experiment) would be more difficult to replicate in the VPLab. LY believed that the impossibility of committing such errors within the VPLab would prevent students from being well prepared for actual lab work.

In his opinion, a very complex simulation would be needed to definitively replace actual lab work in intermediary or advanced courses – the subject believed that making the VPLab that complex (as complex as an industrial simulator, for instance) would be very costly, so that this was not very likely to happen. However, LY did feel that the software (in its actual state) would be perfect for an introductory course if its limitations were clearly exposed to students. Here again, he alluded to situations where a teacher had announced, before specific experiments, that certain aspects of the physical phenomenon under study would be neglected:

I think that this is perfect given that it would be used for an introductory course. I imagine that it would be clearly written, etc. In my opinion, you don't expect more than this – this is what you expect. Anyway, when you do an introductory lab experiment like this, there are some things that you neglect. The teacher says: "Neglect this type of friction or this other thing". For sure, it won't be perfect there either. You expect that too. It rounds off. It's just to show you that it tends towards what theory predicts – you don't see perfect theory. [citation 104]

Adequate precision of instruments and control when performing measurements / Uncertainty of measurement

During the session, LY mentioned that the virtual tape measure was precise enough when used in the VPLab. However, he added that if this tool were to be replicated exactly and used in an actual lab, it would not be precise enough to measure short distances (e.g., 2 cm). He felt that its tape – because it rather appeared to be like a string – would fold or move causing large measurement errors. Hence, in his opinion, a real tape measure designed like the VPLab's would only be precise enough to measure longer distances; for short distances, using a short ruler would be easier anyway.

Concerning the virtual protractor, LY commented favorably on the absence of a function which would have allowed the user to fix the protractor very precisely on the object being measured and automatically obtain a measurement.[140] LY said that the absence of such a function allowed an uncertainty factor to remain when making measurements.[141] He added that such an automatic function would be detrimental to students in a context where learning how to conduct a lab experiment is more important than getting excellent results (and this is the context he anticipated for use of the VPLab.) LY's main impression was that performing measurements oneself without the help of an automatic function was favorable in that context.

When he was asked to assess the uncertainty of length measurements performed with the tape measure, LY proceeded to do so with no hesitation. Afterwards, the subject said that the method he had used to assess uncertainty was the same as the one he would have used in an actual lab. Later, when he was asked whether it was strange or normal that he should be asked to assess uncertainty in the context of working with the VPLab, the subject said:

It's normal: you always have to assess uncertainty on all measurements, with all instruments. [citation 105]

To conclude, we will say that requiring LY to assess uncertainty may have been a cue favoring verisimilitude, and that it felt quite natural for him to do so, at any rate.

Although the affordance of uncertainty of measurement was seen as favorable by LY, the virtual instruments' verisimilitude was diminished when the subject perceived that they lacked precision compared to their real-world counterparts. For instance, LY stated that the virtual protractor was not precise enough since it lacked the detail of graduation he was accustomed to finding on actual protractors (the virtual protractor had a graduation for each 5 degrees but not for each degree).

[140] Such a function is sometimes referred to as a 'snap' feature in CAD software packages.
[141] Here, we must insist that LY made this statement about the presence of uncertainty in a simulation-based environment *before* the interviewer actually required him to assess uncertainty of measurements.

The VPLab's main metaphor (the virtual camcorder, the Analysis workspace's virtual monitor and its Trace function)

During the session, LY had interpreted the Analysis workspace's main display as a device (screen) offering a playback function. The different color schemes used in the Manipulation and Analysis workspaces and the time display had been strong cues for this interpretation. Near the end of the debriefing interview, LY was asked to estimate the probability of finding real-lab equivalents of the functions constituting the VPLab's main metaphor (recording an image sequence, viewing it, and using a trace function). LY answered that finding devices which replicated these functions in an actual lab was probable– that is, in a new school or a school which had kept up to date with recent technologies.

During the session, LY compared the *Trace* function to the carbon paper tracing system which he had used for an experiment conducted in college. He appreciated the fact that the *Trace function* (like the carbon paper system) did not *instantaneously* provide needed information to the experimenter, but instead required him to do further work in order to obtain this information.

Later, when he zoomed in on the image displayed on the virtual monitor (while assessing uncertainty of measurements of distances between traces), he observed that the traces were not identical. The distortion that caused differences among traces was in fact intentionally included by designers, in part, to promote uncertainty assessment– instead, LY believed that it was an unintentional artifact of poor visual presentation, either caused by poor resolution (he thus compared the VPLab to an 8-bit Nintendo video game) or by the process through which the *Traces* were calculated for display.

As a final note, let us say that the metaphor's overall credibility, in LY's case, might have been linked to his prior experience with use of other software which integrated simulations in experimental activities.

Subject MZ

Evaluation of the VPLab's potential to allow performing educational experiments

MZ's rating was 2 (on a 5 point scale) for the VPLab's potential to allow performing educational experiments at a first-year university level. The subject considered that the software would have been much more appropriate for students in high school or college. Some of his reasons will be examined in the next two sections.

The VPLab's main metaphor (the virtual camcorder, the Analysis workspace's virtual monitor and its Trace function) / Task allocation

During the session, MZ criticized the way that the metaphor structured tasks in the experiment. He felt it was strange that the experimenter had to make length measurements on "a television image" in the Analysis workspace instead of making them while handling the apparatus (in the Manipulation workspace). Also, even though he noted great similarities between the Analysis workspace's *Trace* function and a carbon paper tracing system he had previously used, he thought it peculiar that it was not left to the experimenter to decide if traces are to be drawn as the disk moves on the air-table. Here, considerations of verisimilitude and pedagogical value seemed to be intertwined:

> *[…] even from a pedagogical standpoint, I think it's good that one should be required, while performing the experiment, to plan ahead and say:"I'm going to have to leave traces [of the trajectory] to be able to make measurements"*
>
> *Whereas here [i.e., with the VPLab], it's like we don't really care: we move the disk around, then we go to the Analysis [workspace] where we can do anything we want. From this standpoint, maybe it's not very realistic.* [citation 7]

We believe that MZ's abilities and interests in experimental design were conducive to him making these types of judgments.

During the debriefing interview, he further expressed negative judgments concerning the metaphor as a whole. He said that it felt artificial [142] and that he could not imagine, as far as this experiment was concerned, how replicating its functions in an actual lab could be advantageous:

> *I find that making measurements on a television screen, in a simple case like this one, is… well, it's artificial. I can't imagine circumstances where this could be advantageous compared to leaving a trace [on carbon paper].*
>
> *[…] I would tend to say that the approach itself does not seem realistic: to film a sequence so you can later make measurements as on a video image… it's a bit gadgety… However, I imagine it's hard to do otherwise on a computer.* [citation 106]

In this last excerpt, MZ also seemed to appreciate the difficulty of designing a realistic experiment using the computer as a medium.

Uncertainty of measurement (and lack of precision) / "Poor quality" of image following a zoom-in

MZ did consider the possibility of using a camcorder in an actual lab and he suggested ways of avoiding what he saw as the VPLab's most important flaw – lack of precision of measurements:

> *[…] if you're going to film [the experiment], you might as well arrange it so you can get good resolution; you'd get a close-up of the table in order to obtain a better image, for instance … You'd arrange to fix a grid on the table's surface so it would be easier to evaluate distances. It seems to me that these are things you think of almost naturally when you're doing it for real, whereas in [the VPLab], there are big limitations.* [citation 22]

This sensation of lack of precision occurred when the subject realized that the recorded image's quality degraded as he zoomed-in to measure distances between traces more accurately. He first judged this apparent lack of precision in terms of the accuracy that was usually available when using computers, and thus regarded the resulting uncertainty of measurement as an unnecessary consequence of poor visual rendering:

[142] As a side note, MZ felt that if one accepted the concept of working with an image displayed on a "television", it was normal to have to deal with scale conversions. He realized this after he had zoomed-in on the displayed image and noticed that the scale and size of the ruler (which was placed above the virtual monitor) had not changed.

> *I'm aware that this aims to simulate the manipulation [of instruments] but… I know that the computer is powerful enough to give me dots [i.e., position of traces] which are much more precise than this. So this is a kind of false uncertainty. It's just that the dots are too big… In reality, I'm certain that the computer knew very, very precisely where the dots were when it made them.* [143] [citation 23]

Requiring the subject to assess uncertainty may still be seen as favoring verisimilitude; in this case, however, the subject perceived uncertainty as being artificial. Here is what MZ answered when asked if it was useful or rather futile to have to deal with uncertainty:

> *I wouldn't say it is futile, because you always have to deal with uncertainty. I would say that it is artificial. Uncertainty [in the VPLab] is induced by poor resolution of the image. Well…you do have to introduce uncertainty somewhere…* [citation 107]

The subject was then asked to temporarily set aside considerations regarding the uncertainty's source and merely judge whether there should normally be more or less uncertainty in this type of experiment (when done in an actual lab). He felt that the error percentage he had measured for distances between traces was unacceptably high (20%) compared to what he would have dealt with in an actual lab. He later explained that in an actual lab, he would have been able to focus on objects when getting extremely close to them, and thus would have measured them much more accurately than when working with the VPLab.

Measuring instruments

In general, MZ saw the measuring instruments themselves as being "realistic".

A notable exception was the virtual tape measure. He felt that the tape measure was "mysterious" (though very useful) and he thought it highly improbable that this tool could be replicated exactly in reality, its 'inner workings' being very difficult to explain. [144] MZ also mentioned that the tape measure's digital display was useless, given the level of precision that could actually be achieved with this instrument.

Supposing, though, that it could be replicated in reality, MZ said, it could probably be used much the same way as in the VPLab. The subject also commented, on the other hand, that in an actual lab he would rather use a ruler for all length measurements (in the VPLab, at the time of the study, the ruler could only be aligned horizontally and vertically so that it was impossible to use it to measure the length of objects oriented otherwise).

Verisimilitude of the disk's motion on the air-table (deceleration as a sign of residual friction ; spin as a sign of friction with the table's sides) / Complexity of the simulation

The fact that the disk slowed down after having been launched gave this subject an indication that residual friction was working against the disk's motion and this yielded greater verisimilitude. Another cue favoring verisimilitude in this area was the disk's

[143] This is yet another example of the capacity of discerning between a model and its visual presentation.

[144] With the virtual tape measure, the measurement starts at a red circle drawn on the tape measure's plexi-glass casing: MZ could not figure out how the measurement would be processed by the tape measure if it were to be replicated exactly in reality. Also, its tape (which was instead perceived as a string) "seemed to come out of nowhere".

rotation about its own center (spin). [145] This indicated to MZ that friction between the table's sides and the disk (at the point of impact) had been included in the collision model. [146]

During the debriefing interview, MZ was asked to imagine how he would react were he to conduct a full-fledged experiment using the VPLab's air-table simulation and then observe that results had radically strayed from theoretical predictions:

> ***MZ****: My results would be way off, even considering experimental uncertainty ?*
>
> ***Interviewer****:Yes. Maybe that has happened to you in the past ?*
>
> ***MZ:*** *Yes. But in this case, I would tend to say that it would still be my fault. Even if this is software, I would not think that it is the simulation's fault – all in all, the laws of physics pertaining to this are simple enough. I would trust it.*
> [citation 108]

This excerpt may be lead to various interpretations. First, one might say that the simulation's verisimilitude was sufficient during the session, and that credibility was thus promoted. A further interpretation might be that this subject would not expect that the simulation's behavior would be affected by anomalies causing experimental outcomes to radically stray from theoretical predications.

Handling of apparatus / Impossibility of errors in handling apparatus

When he started to handle the disk on the air-table, MZ commented that launching it with the hand-shaped cursor (through 'direct manipulation') was not very precise. He felt that more accurate knowledge of the disk's initial velocity would be necessary for an experiment.

In a similar area of interest, MZ stated also that it was impossible to simulate errors in handling of apparatus. In his opinion, the act of launching the disk too abruptly and damaging it, for instance, could not be simulated in the VPLab.

In a related issue, MZ also said that he would not expect the simulation to present degraded experimental conditions (e.g., the table not being level to the ground). In his opinion, users of the VPLab's air-table simulation would not be able to detect potentially degraded experimental conditions nearly as easily as in an actual lab, and more importantly, it did not seem possible to make adjustments required to correct these defects: hence, students should not be expected to anticipate degraded conditions and should thus be warned of them.

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[145] Some subjects (e.g., BO) also had the opportunity of witnessing the disk's spin but either they did not notice it, or else they chose not to comment on it.

[146] This type of behavior can be observed in everyday life. For instance, one may simply launch a billiard ball against one of the billiard table's sides while giving it lots of spin and watch its behavior after the collision: the billiard ball is most likely to lose most of its spin after the impact. This is due to friction with the table's sides at the point of impact.

APPENDIX D: AN OVERVIEW OF IMPORTANT CUES AFFECTING OVERALL VERISIMILITUDE OF THE VPLAB FOR INDIVIDUAL SUBJECTS

Below, tables D.1 and D.2 present an overview of verisimilitude-related concerns – of considerable importance to particular subjects – for which we could find relations to *specific cues* emerging from the simulated environment. We have organized these tables by theme and by type of cue.

In preparing these tables, we tried to identify the cues which made the most important impact for each of the individual participants. Such a process was admittedly subjective ; this is not to say, however, that we had no criteria for gauging the importance of cues. To some extent, we looked for cues that were spontaneously evoked by subjects during the session, as well as cues and aspects mentioned when subjects were asked general questions relating to overall credibility of the VPLab. Our first finding here is a simple one: different cues and aspects of the simulated environment matter more or less to different individuals.

Bear in mind the following warnings: (1) many of the cues deemed important for some subjects here, might also be of considerable importance to other subjects not mentioned in the table below ; (2) other cues that are absent would also merit examination. In other terms, this is only a sample (albeit, a significant one) of our observations. Most of the cues and themes presented in these tables are analyzed in the main document (and in Appendix C) ; however, other cues and themes not included below have also been tackled.

Table D.1 presents cues connected to *positive* verisimilitude judgments, whereas table D.2 (on page 114) presents cues connected to *negative* verisimilitude judgments. **Keep in mind that descriptions found in the last column reflect *the judgments of subjects* and not those of the author.** It is essential to note that a given cue may have had a positive effect for some subjects, but a negative effect for others.

For instance, one subject (GT) complained about the lack of precision that was induced by having to visually align instruments onto graphical objects – there was no CAD-like 'snap' function to fix instruments very precisely onto objects being measured (see table D.2, under the theme '*Measuring instruments*'). In contrast, another subject (LY) felt that the absence of such a function was favorable – he argued that the user can "do things for himself" and that an uncertainty factor can subsist when making measurements (see table D.1, under the theme '*Freedom and Control over the simulation and the experimental process / Uncertainty assessment*').

Table D.1: Most important cues *positively* affecting individual subjects' overall verisimilitude judgments

Positive "cues"	Subjects concerned	Description of typical judgment relative to cue
Theme: *Behavior of the Manipulation Workspace simulation (The disk's motion on the air-table, in the merry-go-round)*		
Unpredictability of the disk's motion	AN	The disk's motion is unpredictable and thus similar to an actual disk's motion. (This judgment is probably related to observation of the disk's motion after it was launched very precisely in one corner of the table: after going back and forth twice across the diagonal of the rectangular

		table, points of impact with the table's sides started to get away from the corners and collisions started to occur at different places on the sides of the table.)
The disk's slow and uniform deceleration (when the pump is active), and "conservation" of momentum.	BO, CP, FS, GT, HU, JW, LY, MZ	The disk's deceleration implies that air friction working against the disk's motion has been included in the simulation (**CP, FS, HU, JW, LY, MZ**), or that repreated collisions gradually affect the disk's speed (**BO, GT**).
Angles of collision between the disk and the table's sides	BO, GT	Angles of collision between the disk and the sides of the table are similar to those on a billiards table (angle after collision is "opposite" to angle before collision).
Rapid cessation of movement when pump is inactive	GT	It is normal that the disk should stop rapidly when the pump is inactive (i.e, when an air cushion reducing friction does not exist).
Rotation of the disk about its center	GT, MZ	The disk's rotation about its own center, i.e. spin, indicates (to subject **MZ**, at least) that friction between the table's sides and the disk (at the point of impact) has been included in the collision model.
Potential cues that would allow detection or awareness of experimental conditions involving randomness, anomalies and the possibility of making errors	KX	Experimental conditions that would involve randomness, anomalies and the possibility of making errors, would be advantageous as these would help the VPLab become the *"model of a real situation"*.
Theme: *The video clip in the* Presentation *multimedia document and Discursive cues in the multimedia documents*		
The video clip	BO, FS	The video clip "shows the experiment done with real objects" (subject **BO**). When the simulated disk's motion is compared to that of the disk depicted in the video clip, it is extremely similar. Therefore, the VPLab has much potential in allowing to perform physics experiments (subject **FS**).
Discursive cues concerning the simulation's complexity: (1) The *Presentation* multimedia document (it "sets the tone" for the simulation's complexity). (2) Theoretical explanations contained in the *Explanation* multimedia document / Potential mathematical and theoretical information accompanying the simulation in order to justify its behavior.	LY	The *Presentation* multimedia document describes (or should describe) how complex the simulation is compared to reality and why there are deviations from reality, if any. This makes the simulation's behavior meaningful. The theoretical explanations (in the *Explanations* multimedia document) which contained animations of the disk's motion (including vectors) will promote trust in the simulation. More disclosure is needed. Real-time mathematical and theoretical descriptions (and justifications) of the simulation's behavior (e.g., real-time exposition of formulas and calculations needed to render simulations) would promote trust.
Theme: *Freedom and Control over the simulation and the experimental process / Uncertainty assessment*		
Free interaction and freedom to choose methods	BO, HU	The freedom not to follow a (tutorial-like) pre-established path (**BO**) and the freedom to choose measurement methods and calculating methods (**HU**) are favorable – examples of the latter include the possibility of setting the number of *Traces* and the interval between them, or the lack of constraint forcing one to perform uncertainty assessment combined with the possibility of doing so, if one wishes.

High degree of control over objects / Direct manipulation conventions / Affordance of errors on measurements	BO, GT, HU, FS, LY	'Direct manipulation' conventions: using the hand-shaped cursor and mouse to directly handle the apparatus in a variety of ways (**BO**) is favorable ; not having to enter parameters with the keyboard to get feedback in return (**FS**, **GT**) is also favorable. It is the user who performs the measurements, and *not* the computer (**HU**), so that the situation is "really experimental": it is supposed that a given number of individuals measuring the same distance could obtain just as many different measurements. The *absence* of a CAD-like 'snap' function (allowing the user to fix the protractor very precisely on the object being measured and automatically obtain a measurement) is favorable (**LY**). The absence of such a function allows an uncertainty factor to subsist when making measurements. Users can do things for themselves.
Theme: *Instruments, Objects measured, and Data collected*		
Types of instruments	CP, IV, KX	The types of instruments used are likely to be the same as in an actual lab (**CP**). In a broad sense, data is collected the same way as in a real lab (**KX**, **IV**), as "all the instruments have been provided so that [one] can obtain the same data as [one] would want to obtain in a lab".
Instruments looking like they can be handled with one's hands	GT	The instruments look like they can be handled with one's hands – this is a "realistic" aspect found in video games.
Some instruments can be handled as expected (e.g., the virtual tape-measure)	IV	Use of the virtual tape measure is enjoyable and its "way of functioning" is the same as for a "real tape measure".
Types of objects being measured and quantities derived from the measurements.	CP, IV	The objects being measured – distances between *traces* (dots), angles, etc. – are likely to be the same as in an actual lab experiment (**CP**, **IV**). The quantities derived from the measurements – e.g., the disk's velocity – are also likely to be the same (**CP**).

Table D.2: Most important cues *negatively* affecting individual subjects' overall verisimilitude judgments

"Negative" cues	Subjects concerned	Description of typical judgment relative to cue
Theme: *The VPLab's main metaphor* *(The virtual camcorder and the virtual monitor with Trace and Zoom functions)*		
The metaphor itself and its task allocation	MZ	It feels artificial and "unrealistic" to film a sequence and then to take measurements, as on a video image. Also, there are drawbacks in terms of pedagogical effectiveness because the metaphor's allocation of tasks is not conducive to thinking ahead about the methods one should use (*planning ahead*).
The requirement of having to perform scale conversions of measurements	CP	Performing scale conversions of measurements does not correspond to anything that is part of actual lab work.
Too many steps in the process of measuring lengths / Using the Zoom function	HU, CP	Performing measurements within the VPLab is more fastidious than in a real lab (**HU**). There is no need for a *Zoom* function in a real lab. (**HU, CP**)

Traces ‘moving along’ ahead of the object in motion	CP, ER	When comparing to carbon paper markings, it seems strange and impossible that there should be traces ahead of the object in motion (the disk’s image) during playback.
Adding and removing *traces* in the Analysis workspace	DQ	It is very difficult to imagine how one could add and remove traces at will so easily in the context of a real experiment.
Lack of precision resulting from degraded graphical quality after zooming in on the recorded image.	MZ	The uncertainty of measurement which results from zooming in on the image is an unnecessary consequence of poor visual rendering. In an actual lab, there would be easy solutions allowing an experimenter to obtain much more precision.
Theme: *Graphical attributes and visual presentation*		
The colors and textures of the apparatus depicted in the Manipulation and Analysis workspaces / Game-like graphical attributes	ER, FS	Lower visual fidelity: the color schemes (blues, violets and yellows) emphasize the fact that the images of the VPLab’s apparatus are drawings (**ER**). The Manipulation and Analysis workspaces’ graphical attributes are “attractive” and “game-like” and, as such, create expectations of lower complexity in the simulation’s behavior (**FS**). Moreover, the images are not photo-realistic, its textures could be improved, and the colors could “look more real”.
Seeing the apparatus in a narrow space	ER	Seeing the apparatus in a narrow space is annoying and it would be preferable to see the whole air-table in large.
Theme: *Instruments*		
Appearance of the instruments / Types of instruments: “Unreal” instruments (calculator and tape measure) / A ‘gadgety’ interface	ER	The calculator and tape measure do not seem “real”: the VPLab’s tape measure and calculator are not similar to those encountered in the real world. The interface has many gadgets– this is distracting.
Measuring instruments cannot be handled as expected or were less intuitive than in the real world	ER, IV, LY	Some instruments – like the virtual tape measure – should be as intuitive to use as their real counterparts (**LY** had not been able to find tape measure’s reference points for the beginning and the end of the measurement.) The tape measure does not behave the same as its referent (**ER**). The virtual ruler and protractor do not allow for arbitrary rotations, but are restricted to 90-degree turns (**IV**). It would be more ‘realistic’ and satisfactory to be able to smoothly spin these instruments just by ‘dragging’ a corner in a circular motion.
Perceived lack of precision when visually aligning instruments with graphical objects / Impossibility of “snapping” instruments onto graphical objects being measured	CP, GT	There is an unwarranted lack of precision when visually aligning instruments onto graphical objects.(**CP, GT**) It is not possible to use a CAD-like ‘snap’ function to fix instruments very precisely on the object being measured and thus automatically obtain precise measurements. (**GT**)
Theme: *Control*		
Feeling a lack of control over objects / Impossibility of handling objects with one’s hands	DQ, JW	A feeling of lack of control over objects is experienced. It is impossible to control objects with one’s hands (**DQ**) Working with a mouse instead of manipulating apparatus and instruments with one’s own hands is detrimental to comprehension (**JW**).
Lack of precision when launching	GT, KX	It would be preferable to be able to control the disk’s

the disk		velocity and direction more accurately. Use of the mouse is to be blamed for this lack of precision. (**KX**) In a real lab, one could know what force has been applied when launching the disk with the elastics which line the table's sides. In the VPLab's simulation, one cannot set the initial position of the disk before its launch as precisely as in an actual lab. Additionally, one would be able to launch the disk faster in an actual lab. (**GT**)

APPENDIX E: THE ISSUE OF PRESENCE / TANGIBILITY / DIRECT CONTROL OVER OBJECTS WITH ONE'S HANDS

As we have mentioned, the issue of *presence* (Steuer, 1992) is somewhat independent of verisimilitude and was not the main focus of our work. Nevertheless, it did come up in the course of our research. As one may still be interested in perceptions of presence/tangibility in environments like the VPLab, we will expose some of our observations in this area.

Several subjects commented that they felt a 'lack of tangibility' or a lack of direct control over (simulated) objects.[147] Although different judgments pertaining to 'lack of tangibility' did present commonalities, there were also important nuances between the attitudes displayed by different subjects. For some, *tangibility/control/presence* was an issue of major importance (e.g., subjects AN, BO, DQ, FS, JW, and perhaps KX [148]): these participants seemed to be significantly affected by what they perceived as a lack of tangibility (e.g., subjects AN, BO and FS) or by not being able to directly control objects with their own hands (e.g., subjects DQ and JW). For others (e.g., GT, HU, IV and LY), this seemed to be an issue of somewhat lesser importance, but worth mentioning nonetheless. We have chosen to describe cases where *tangibility/control/presence* was an issue of major importance.

Subject AN's attitude was associated with a lack of presence which, he felt, could be remedied by potential technological improvements (e.g., an immersive virtual environment or 3D graphics) and which had little relation with the VPLab's ontological status as a computer simulation, per se.

Subject FS's feeling of lack of presence was associated to what he perceived as the simulated environment's shortcomings. In slight contrast to AN, there was some contradiction in FS's opinion regarding the possibility that eventual technological improvements might counter this lack of presence. On the one hand FS believed, for instance, that an *immersive* virtual environment could not provide the experience of feeling inertial forces (created by the merry-go-round's rotation) – and somewhat related to this was the question of doubt created by the VPLab's ontological status as a virtual environment. On the other hand, FS also proposed that photo-realistic images – including elements such as "**a nicer texture**" , as well as **instruments** and **colors** that "look more real" – may help provide "a greater impression that [the environment] is real", and would thus promote a greater sense of presence in the environment:

> *Of course, the nearer it gets to reality, the more you will feel part of that world. You'll forget your surroundings and you'll really concentrate on [the simulation].* [citation 61]

Another subject (BO) displayed an attitude which revealed doubt towards the simulated environment. This doubt seemed to be directly related to the fact that the VPLab's objects were computer generated images– *ipso facto*, this concerns the VPLab's ontological status. As well, we note a strong relation to the question of presence:

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[147] Some of those judgments regarding 'tangibility' could fall under the heading of *recognition of absence* of modality judgments (Chandler, 1997).

[148] It is not too clear whether or not this was an issue for subject KX because he only mentioned that students would understand and learn more if they could do the experiment "concretely" in an actual lab.

[An immersive virtual environment] is still numerical – the images are drawn or made with a computer.
But if you see it… You know, if you see someone in weightlessness on television, it's not the same as actually being in weightlessness yourself. [citation 46]

We also deduce from this excerpt that watching photo-realistic images is also an experience that lacks presence, in the subject's opinion; the link between his attitude and the VPLab's specific nature is thus somewhat weakened.

For his part, subject DQ felt that "it wasn't real on a computer" ; this feeling seemed to merge with a sensation of lacking direct physical control over objects. Contrary to others, his sensation would not be diminished, in his opinion, by potential technological improvements, and seemed more tightly related to the question of ontological status.

JW's attitude – expressed through negative comments over not being able to handle objects with his own hands and "not seeing things in front" of him – was similar to BO's and DQ's attitude in that it was somewhat linked to doubt caused by the VPLab's ontological status. JW's stance was also very close to DQ's stance, in that it was linked to the impossibility of controlling objects with his own hands.[149] However, JW was very ambivalent when asked if technological improvements (e.g., better graphics or working in an immersive virtual environment) could diminish this feeling.

In short, even though there were similarities across subjects in this area, there were also appreciable variations. For each of the participants we have mentioned, a host of factors (the VPLab's ontological status, not controlling objects with one's hands, different feelings which the simulation could not provide, potential change entailed by possible technological improvements, etc.) were combined somewhat distinctly in the expression of specific judgments.

[149] During the preliminary interview, both DQ and JW stated that 'touching' objects had been essential to prior lab work because it had allowed them to have a better grasp of phenomena. This trait, however, was also shared by other subjects (e.g., ER, IV and FS).

APPENDIX F: LIST OF ORIGINAL SUBJECT QUOTES IN FRENCH (TRADUCTION DES CITATIONS)

Here is the list of original quotes as uttered by subjects who participated to this study which, as we recall, was conducted in French (in Québec, Canada). Each of the subject quotes in this report is followed by a number within brackets [e.g., citation x]. This number refers to the number contained in the first column of the following table.

{Voici la liste des citations originales en français. Dans ce rapport, chacune des citations des sujets est suivie d'un numéro entre crochets [citation x] qui se réfère au numéro de citation, dans le tableau ci-dessous.}

Quote Number	**English translation**	**Original quotes as uttered by subjects in French**
1	LY: […] you'll always have limitations: is this really representative of the theoretical model ? What's behind this [simulation] to make [the disc] move like that ? Did [the programmer] take a formula and simplify it to allow for nice motion ? […] That's what bothers me: you have this software but you can have it do anything you want. […] Of course, you tell yourself that they are teaching a class so they won't hand you any old thing. That not withstanding though, 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 saying nonsense. With [the VPLab], you can't really question things because there's an [intrinsic] limit in using the program itself: if you start to question things at home like that, you lose the whole purpose of using the software. You don't know 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 x happens, [the disc] automatically goes the other way... Or does it really work with a formula, with all values truly changing according to reality? […] Interviewer: So it's really a question of credibility in what the simulation can produce compared to… LY: Yes, a question of credibility and [of knowing that] the principles are clear – that things aren't too hidden. Interviewer: So more disclosure is needed ? LY: Yes.	LY : […] tu vas avoir toujours des limitations. Ces limitations là c'est : est-ce que c'est vraiment représentatif du modèle théorique ? Qu'est-ce qu'il y a derrière [le mécanisme sous-jacent] qui fait que ça [le disque] bouge comme ça ? Est-ce qu'il a pris une formule et qu'il l'a simplifié pour que ça fasse un beau mouvement ? […] C'est ça qui me fatigue : tu as le programme mais tu peux faire dire n'importe quoi à un programme. C'est certain que tu te dis : "Bon, ils donnent le cours, ils ne te donneront pas n'importe quoi ?". Sauf que, même là, ils disent toujours de prendre comme si c'était pas vrai et ils fallaient qu'ils te prouvent que c'est vrai. […] ils disent qu'il faut toujours te questionner sur ce que le prof. dit. Peut-être qu'il dit n'importe quoi. Avec ça [le LVP] tu ne peux pas vraiment te questionner parce que c'est limité dans le programme. Si la personne commence à faire ça chez elle, tu perds le principe du logiciel [le logiciel est rendu obsolète]. Tu ne sais pas si le programmeur a vraiment pris le temps de tout inclure les choses - vraiment tout prendre les aspects théoriques et de faire vraiment les vrais calculs - ou il a juste foutu quelque chose parce qu'il dit : "Ça va donner ça". Il y a toute une table déjà faite : quand il arrive telle chose, automatiquement, [le disque] part de l'autre côté. Donc, tu ne le sais pas si c'est vraiment... ou si c'est une formule qui agit, et que toutes les valeurs, à chaque fois, changent vraiment selon ce qui est vrai. […] Animateur : Donc c'est vraiment une question de confiance en ce que la simulation peut donner par rapport.... LY : Oui, question de confiance et c'est vraiment [de savoir si] c'est claire comme principe - que c'est pas trop caché. Animateur : Il faudrait plus de transparence ?

		LY : Oui.
2	[If] you do not have control over anything [and you follow some preestablished path], 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 disc for 15 minutes – you see that it's not really programmed… **there is programming but it respects what happens in real life.**	[Si] tu n'as le contrôle sur rien, là quelqu'un va être plus sceptique [et pourra] dire: "C'est programmé pour faire ça". Tandis que si quelqu'un contrôle - de bouger et de toucher à tout ce qu'il veut ; de lancer et de s'amuser avec le disque pendant 15 minutes, puis qu'il voit que c'est pas vraiment programmé... **une programmation oui sauf que ça respecte ce que ça fait dans la vraie vie.**
3	DQ: […] When you're on a computer, it's not real. I think that's the biggest difference, between the two. When you're in a lab, you're the one who's manipulating, you're the one who's measuring, you're doing everything – when you're on a computer, you use the keys but you're not the one who's in control, you're not controlling, with your own hands, the things that you do. Interviewer: Right now, is that also the case ? It's a question of controlling things more directly with your own hands… DQ: For me, that's the big difference between software like this and a practical lab. Interviewer: What type of consequences does manipulating things with one's hands entail, compared to doing things like this [with the VPLab] ? Do you see repercussions on the experiment's results ? How does it change the way you do the experiment ? DQ: I think it doesn't give the same result. Ideally, in my opinion, you should be in a lab but software like this can be a fine complement. Interviewer: Does manipulating things have an impact on what you can learn and the errors that you can make ? DQ: Sure, because [in a lab], if you make a mistake, if anything is wrong, you'll see it and you can readjust things. I think you have more control when… with equipment, when you're manipulating it. The disadvantage of a computer simulation is that you're not controlling everything. Even if you're controlling things with your keyboard and your mouse, it's not real – it's not the same.	DQ : […] Quand t'es sur un ordinateur, c'est pas réel. C'est la plus grosse différence, je pense entre les deux. Quand t'es en laboratoire, c'est toi qui manipule, c'est toi qui règle tes choses, qui prend les mesures, c'est toi qui fait tout – tandis que sur ordinateur, tu joues avec des touches mais c'est pas toi qui a le contrôle, c'est pas toi qui contrôle avec tes mains ce que tu fais... Animateur : Dans le cas qui nous occupe, c'est ça aussi ? C'est une question de contrôler les choses avec nos mains, plus directement.... DQ : Moi, c'est la grosse différence que je vois entre un logiciel comme ça et un laboratoire pratique. Animateur : Quel genre de conséquences ça entraîne, le fait de manipuler les choses avec ses mains, par rapport à faire ça comme ça [avec le LVP] ? Est-ce que tu vois des répercussions sur les résultats d'une expérience ou la façon de faire une expérience ? Comment ça change la façon de faire une expérience ? DQ : Je ne pense pas que ça amène le même résultat. Selon moi l'idéal c'est d'être en laboratoire mais comme complément ça peut être bon un logiciel comme ça aussi. Animateur : Le fait de manipuler des choses, est-ce que ça un impacte sur ce qu'on peut apprendre ou les erreurs que l'on peut faire ? DQ : C'est sur parce que [en laboratoire] si tu te trompes, si jamais il y a quelque chose de pas correcte, tu vas le voir, tu peux réajuster tes choses - je pense que t'es plus en contrôle quand... avec le matériel, c'est toi qui manipule. Le désavantage d'une simulation sur ordinateur, c'est que c'est pas toi qui contrôle tout. Même si contrôle avec ton clavier et ta souris, c'est pas réel, c'est pas la même chose.
4	Interviewer: Have you ever seen movies or news reports on virtual reality – of people who wear helmets and gloves ? DQ: Yes, I've seen that a few times. Interviewer: What would you think of a [virtual reality] lab where you could manipulate things	Animateur : Est-ce que tu as vu certains films ou reportage sur la réalité virtuel - des gens avec des casques et des gants ? DQ : Oui, j'ai déjà vu ça un peu. Animateur : Qu'est-ce que tu penserais d'un

	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 [problem]. It remains imaginary… well, imaginary, in a way of speaking. It's not imaginary but it's not real.	laboratoire comme ça où tu pourrais manipuler des choses avec des gants - ça serait des objets - il y a certains gants qui donnent des sensations tactiles ? Je me demandais si le problème était de travailler avec une souris et un clavier ou si c'était la même chose pour toi avec un casque et des gants ? DQ : C'est la même chose. Ça reste dans l'imaginaire - bien imaginaire entre parenthèses, c'est pas imaginaire mais c'est pas réel.
5	JW: […]I think that there are some things, 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 disc 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 ? FS: Yes, it's the fact that I don't do things with my own hands – that I don't really look upon it…	JW : […] je pense qu'il y a certaines choses que même si on le voit ici [elle pointe l'écran], on a l'impression que ça pourrait tout être manipulé. Par exemple, quand on voyait le disque qui bougeait comme ça dans le vidéo, ça se voyait que c'était vrai, mais […] ça l'air moins réel dans l'ordinateur, quand ce n'est pas un vidéo. Quand on le fait dans un labo, tu le vois avec tes yeux. Là [elle pointe l'écran], tu le vois avec tes yeux mais […] il y a machine qui a fait tout ça. Animateur : Donc, c'est le médium lui-même ? FS : Oui, le fait que je ne le fais pas avec mes mains. Que je ne le regarde pas comme ça...
6	It's a computer, [so] everything goes well: there would be no physiological problems in the apparatus. And also, when you experiment [in an actual lab], you do it yourself – you see… you'll know if a piece of dirt [on the table] has deviated the projectile… but in this case [i.e. with the VPLab], I don't know if you can physiologically perceive the anomalies. Anyway, it's good that these types of errors exist [in the VPLab].	C'est un ordinateur, ça se fait tout bien : il n'y a pas d'erreur physiologique du montage. Puis c'est que quand tu l'expérimentes, quand tu le fais toi-même, tu vois - tu peux soit savoir [que c'est] une mine de crayon sur le truc qui a fait dévié mon affaire sauf que là, je ne sais pas si tu peux voir les anomalies physiologiquement. Mais c'est bon quand même qu'il y a des erreurs comme ça.
7	[…] even from a pedagogical standpoint, I think it's good that one should be required, while performing the experiment, to plan ahead and say:"I'm going to have to leave traces [of the trajectory] to be able to make measurements" Whereas here [i.e. with the VPLab], it's like we don't really care: we move the disk around, then we go to the Analysis [workspace] where we can do anything we want. From this standpoint, maybe it's not very realistic.	[…] même d'un point de vue pédagogique, je trouve que c'est bien d'avoir à prévoir immédiatement au moment de faire l'expérience [quand on fait les manipulations] - d'avoir en tête le but - donc d'être capable de dire immédiatement : "Il va falloir que je laisse une trace pour prendre mes mesures" Alors que là, on dirait qu'on s'en fou un peu, on s'amuse à faire déplacer [il se rend à l'espace de manipulation]- on s'en va dans l'analyse puis maintenant [il retourne dans l'espace d'analyse] on peut faire ce qu'on veut. Donc pour ça, c'est peut-être pas très réaliste.
8	Interviewer: So this [video] is important ? B.O: Well 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 experiment done with real objects.	Animateur : Donc c'est important ça ? B.O : Bien oui, ça ne fait pas juste... Tu sais.... du monde sceptique qui dit : "Oui, c'est arranger. C'est un logiciel, c'est sûr que ça va marcher comme ça. J'ai juste à cliquer puis à suivre le cheminement." Avec l'extrait vidéo, ils voient que c'est pas juste du logiciel - c'est pas juste une simulation où tu cliques là et ça va faire telle chose. En fin de compte, ça te montre l'expérience qui est fait avec des vrais objets.
9	BO: That's why it's useful to see the video clip	B.O : C'est pour ça que c'est utile de voir le vidéo

	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 of the disc'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.	avant. Ça montre que... Ça amène une introduction donc quelqu'un qui arrive ici et qui part le manège, il n'est pas surpris de la courbe prise par le disque. Animateur : Parce qu'autrement, on serait surpris ? BO : Bien les profanes seraient surpris, pas les initiés. Ceux plus qui ne réfléchiraient pas : "Ah, quand tu y penses 2 secondes, tu le sais que ça va tourner parce que c'est dans un référentiel qui tourne." Animateur : La façon dont il tourne, est-ce que ça te paraît... BO : Non, ça l'aire normal par rapport au vidéo qu'ils ont montré tantôt.
10	Interviewer: What was happening before you stopped the pump ? CP: The disc was moving. It slowed down – there is a loss of speed, of course. Interviewer: Why ? CP: There is some friction ; it's not totally absent. Interviewer: What do you think about the fact that there is friction ? Did you expect that ? CP: Well yes. Air creates friction. It is impossible [not to have friction] unless… We neglect it a lot [in calculations] but it's there all the same. **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 discs so they slow down faster. I don't know if…**	Interviewer : Qu'est-ce qui se passait avant que t'arrêtes la pompe [avant que T9 arrête la pompe, le disque allait très lentement] CP : Mon disque bougeait. Il ralentissait là, c'est sur que tu perds de la vitesse... Interviewer : Pourquoi ? CP : Il y a quand même une friction, c'est pas SANS friction TOTALE. Interviewer : Et comment tu trouves ça qu'il y ait tout de même de la friction ? Est-ce que tu t'attendais à ça ? CP : Ben oui. Il y a l'air qui crée une friction. C'est impossible[pas de friction] à part de... On la néglige [pour les calculs] de beaucoup mais il y en a quand même. **Interviewer: Donc c'est normal que l'on voit un certain ralentissement ?** **CP :Oui. et ça corrobore beaucoup ce qui se passe en laboratoire. En laboratoire, c'est des disques d'acier par exemple, donc ils ralentissent plus rapidement. Je ne sais pas si…**
11	wasn't really a relation between content [and graphical quality]	[la qualité graphique] Ça n'a pas vraiment rapport avec le contenu
12	[The VPLab] is somewhat like SimCity [the videogame] 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.	Ton logiciel est fait un peu comme Simcity où tout est tenu en ligne de compte. Ça c'est des logiciels qui sont quand même assez - l'interface graphique n'est pas réaliste - [mais] tu regardes ce qui arrive et c'est vraiment réaliste […]
13	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 LVP] 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	BO : […] le graphisme - le fait que ça soit pas terne. Parfois, vu que c'est en physique, ils sont obligés de mettre ça plate. Souvent les manuels et les vidéos des années 50 qui nous présentent dans les cours - c'est en physique. Animateur : Est-ce que ça fait moins sérieux comme ça [comme le LVP] ?

	doesn't have to be boring for you to learn something. […]	BO : Non. Au contraire, je trouve que ça ouvre des portes. Ce n'est pas parce que c'est laid que c'est sérieux. Ce n'est pas parce que c'est plate que l'on va apprendre quelque chose. […]
14	[…] 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…	tous les éléments sont là pour faire comme si j'étais en laboratoire. Tous les instruments sont fournis pour arriver à prendre les mêmes données que j'aurais voulu prendre en lab - c'est ça qui est important je pense…
15	In video games, we often see this – a logbook or a camera. [The VPLab's camcorder] is designed in a very real… very realistic way: you can almost manipulate it… with your fingers. You click on a button with the finger [i.e., pointer] and it closes [the camcorder's screen] automatically. So it's very realistic, it's gadgety […] You don't enter functions with the keyboard – it's almost always done with the mouse and a hand [i.e., pointer] on the screen.	Dans les jeux vidéo, on a souvent ça - admettons un logbook ou une caméra. C'est fait d'une façon très réelle, très réaliste : on peut presque le manipuler comme... avec nos doigts. On a le bouton ici [il pointe le bouton qui permet de replier l'écran du caméscope] avec un doigt [à ce moment, le curseur est une main avec l'index qui pointe] - on clique dessus [il replie l'écran], ça se range automatiquement. Donc c'est très réaliste, c'est gadget. […] c'est pas les fonctions qu'on tapent sur le clavier, c'est presque tout le temps avec la souris puis une main à l'ordinateur
16	tape measure's "way of functioning" was the same as "a real tape measure"	Ça marche comme un vrai ruban à mesurer de Papa.
17	The protractors that I've used before had a calibration that was [detailed] to the one-degree mark. We would really see the one-degree mark… so the level of precision [of those protractors] is a bit higher [than that of the VPLab's protractor]. So this one may not be precise enough. I would say "2" - a low probability […] because it's not precise enough for a physics lab.	Les rapporteurs d'angle que j'ai utilisé - la calibration est faite au degré. On peu vraiment voir le degré donc le niveau de précision est un peu plus élevé [que celui du LVP] Donc celui-là est peut-être pas assez précis. Peu probable [2]. Je dis que c'est peu probable parce que c'est pas assez précis pour un laboratoire de physique.
18	GT: Us [engineers], we're used to plugging numbers into formulas – numbers with lots of decimals. It's also a very serious field, very conservative […] This is software which is attractive, it's gadgety […] but it's not the type of software we… we use things that are only technical and that's why I was disconcerted. Interviewer: OK. You weren't in your own world. GT: That's it ! Exactly. A drawing like this [protractor] interferes with my real world […] In my real world, I could take these instruments, play around with them on a table and use the ruler, in my own way, to perform measurements. However, in this case, I can't touch [the instruments] and **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.**	GT : Nous autres [les ingénieurs], on est habitué de 'plugger' des chiffres dans des formules - des chiffres avec plusieurs zéros après la virgule. C'est aussi très sérieux le domaine, c'est très conservateur […] Ça [le LVP] c'est un programme - c'est beau, c'est gadget […] mais ce n'est pas le genre de programme- nous autres, comme je te dis, on utilise des choses qui sont juste techniques […] c'est pour ça que j'ai été dérouté. Animateur : O.K. Tu ne te retrouves pas dans ton monde. GT : C'est ça. Exactement ! Un dessin de ça [il déplace le rapporteur], ça interfère avec mon monde vrai. Dans mon monde réel, moi je pourrais prendre ces outils là et jouer avec sur une table [il fait semblant de manipuler des objets sur le bureau] et vraiment mesurer comme je voudrais avec [?mon rapporteur?] et ma règle. Mais ici, je ne peux pas y toucher et **il faut que je me fie à un écran qui a un ZOOM, qui a des échelles et que c'est des pixels dans le fond. C'est vraiment à l'œil et je ne peux pas être sûr que je suis vraiment centré ou... visuellement, c'est difficile à dire.**

19	Well, it's because [the tape measure] is between… Because, given the fact that [the VPLab] is a computerized system, you tell yourself that it is going to measure precisely – direct, precise, real values. But this is rather somewhere between taking precise values and taking values that refer to something that would be collected manually. So because it's between the two, I'm having a bit of difficulty …	Bien, c'est le fait que ça soit entre un... Parce que vu que c'est un système d'ordinateur, tu te dis que ça va mesurer précisément, directement des vraies valeurs précises. Tandis que là, c'est un peu entre quelque chose qui prend des valeurs précises et quelque chose qui prend des valeurs comme - qui réfère à quelque chose que l'on prendrait manuellement. Donc là, comme c'est entre les deux, j'ai de la misère un peu à voir.
20	[..] If you didn't ask me, I would surely say that [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.	[…] Si on ne me le demande pas, je vais sûrement dire : "C'est précis." Mais il y en a toujours une [incertitude] ; c'est pour ça que... ils veulent plus mettre la réalité là-dedans, je veux dire.. […] ils veulent plus se rapprocher de la réalité alors ils veulent nous faire prendre des incertitudes pour qu'on soit vraiment en train de travailler.
21	[…] 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.	[…] c'est vraiment expérimental dans le sens où, la distance entre les points, c'est nous qui la mesurons Si dix personnes la mesure, il peut y avoir dix réponses différentes.
22	[…] if you're going to film [the experiment], you might as well arrange it so you can get good resolution ; you'd get a close-up of the table in order to obtain a better image, for instance … You'd arrange to fix a grid on the table's surface so it would be easier to evaluate distances. It seems to me that these are things you think of almost naturally when you're doing it for real, whereas in [the VPLab], there are big limitations.	[…] tant qu'à filmer, tu t'organise pour avoir une bonne résolution, tu permets à la caméra de zoomer seulement sur la table pour avoir une meilleure image par exemple.... Tu t'organises pour avoir un quadrillé sur la table pour que ça soit plus facile d'évaluer les distances... Il me semble que c'est des choses auxquelles on pense presque naturellement au moment où on le fait pour de vrai et dans ce cas là elles sont assez limitées.
23	I'm aware that this aims to simulate the manipulation [of instruments] but… I know that the computer is powerful enough to give me dots [position of traces] which are much more precise than this. So this is a kind of false uncertainty. It's just that the dots are too big… In reality, I'm certain that the computer knew very, very precisely where the dots were when it made them	Je sais bien que c'est une simulation de manipulation là... mais... je sais que l'ordinateur est assez puissant pour me donner des points beaucoup plus précis que ça. Donc, c'est une espèce de fausse incertitude là. Bon, c'est juste que les points sont trop gros.... alors qu'en réalité je suis certain que lui, l'ordinateur, au moment où il l'a fait [calculer la trajectoire], il savait très, très précisément où était les points.
24	I do everything, basically. See here: I determine the number of dots [i.e. traces] and the interval [between them] myself, as I want… 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.	On fait tout dans le fond. Comme ici, c'est nous qui déterminons le nombre de points [traces] que l'on veut ; quel intervalle que l'on veut... Je peux prendre par exemple, cinq mesures et ça va être cinq mesures différentes à 1 ou 2 mm près et après faire la moyenne de ces cinq mesures pour avoir une distance plus précise. Lui [l'ordinateur] ne le fait pas à notre place. C'est nous autres qui choisissons vraiment les méthodes de mesure, nos méthodes de calcul. [...] C'est nous qui choisissons notre manière de procéder.
25	I was a bit confused. It wasn't very clear in my mind that it was a computer simulation. I thought of it more as if it was video. So… I could lower	J'étais un peu mêlé là-dessus. J'avais pas vraiment éclairci mon idée que c'était une simulation informatique. J'y réfléchissais comme si c'était de la vidéo comme modèle. Bien... je pourrais juste

	[my rating] a bit.	baisser un peu plus.
26	when you see what really happened, it's a video	quand tu vois ce qui s'est passé réellement, c'est de la vidéo.
27	BO : Well, one classmate told me that if [the VPLab] was available, he would get it. This friend who spoke to me doesn't like physics. And he told me : "It [the VPLab] helped me to understand things that I hadn't understood in class". [On the sole basis of] having done the test here, he said that [the VPLab] looked like it was really well designed and that, although he isn't a physics student, this would be the kind of software he would buy. But no, they [i.e. other subjects] did not say anything of… I was not aware of… Interviewer : I'm just curious… Did they mention any of the questions [that you would be asked here today] ? BO : No.	BO : Bien il y en a un qui m'a dit que s'il était disponible, il le prendrait. Que c'était le genre de logiciel... Mon ami à qui j'ai parlé n'aime pas la physique. Et il m'a dit que "Ça m'a aidé à comprendre des choses que dans mes cours, je n'avais pas compris." Juste en venant faire le test ici, il disait que ça avait l'aire vraiment bien fait et que même si on n'était même pas en physique, ça serait le genre de logiciel qu'il achèterait. Non mais il ne m'ont pas dit rien de... Je n'étais pas au courant de... Animateur : Je suis juste curieux... Est-ce qu'ils t'ont parler des questions ? BO : Non.
28	CP: [...] everything can be manipulated… Well, notice that today, if I show you a video clip, it can be created from A to Z on a computer and it is fictive. […] Interviewer: For you, the difference between the two [simulation and video], is it still… CP: No, as far as I'm concerned, there is no difference [between] a video and a computer because both can be manipulated. If you've seen the movie Star Wars [Episode One], there is [only] one scene that was truly filmed ; but for the rest of the movie, you say: "My God, is it real ? It seems real !" And it was all done with computers but you'll watch it on your TV screen.	CP : […] ça peut tout être manipulé... remarque que aujourd'hui, je te montre une séquence vidéo et elle peut être montée par ordinateur de A à Z et c'est fictif. […] Animateur : Pour toi, la différence entre les deux, est-ce qu'elle est encore... CP : Non, pour moi, un vidéo ou un ordinateur, il n'y a pas de différences parce que les deux peuvent être manipulés. T'sais, si tu as été voir le film Star Wars, il y a une scène qui a été tourner pour vrai ; le restant du film tu dis : "Mon dieu, c'est-tu vrai, ça l'air vrai !" Ça tout été fait par ordinateur mais tu l'as dans ton écran de T.V.
29	ER: Chances are better that things really happened if they were filmed then if they are depicted with images. Interviewer: Would the video clip and the computer simulation be about equal for you ? ER: No… I would prioritize video. Interviewer: On a scale of 1 to 5 ? ER: Video would be higher than simulation.	ER : Il y a plus de chance que ça se soit passé pour vrai si c'est filmé que si c'est représenté par présentation imagée. Animateur : Et pour toi, est-ce que tu penses que ça serait à peu près égal la séquence vidéo et la simulation informatique ? ER : Non... je mettrais assez en priorité le vidéo. Animateur : Sur une échelle de 1 à 5 ? ER : [Je mettrais] le vidéo plus [élevé] que la simulation.
30	I have to touch things, so simulations will often work so-so [for me].	Moi il faut que je touche. Donc souvent, les simulations ça va être so-so (comme ci, comme ça).
31	A computer simulation of something that is itself normally controlled through a computer [e.g.: a nuclear reactor] will work well. However, if you simulate something like a jib-crane, the [operator] gets on the crane and if manual operations are required, then he will have difficulties because [..]	Une simulation sur un ordinateur qui simule quelque chose qui se contrôle normalement à l'aide d'un ordinateur, ça marche bien.[Central nucléaire]. Mais si tu fais une simulation d'une grue, le gars arrive dans la grue et si c'est des opérations manuelles, là il va avoir de la misère

	this requires “manual feel” and he’ll never know that. And you have a phenomenon [associated with] the power [of the machinery] – it’s not the same.	parce que […] quelque chose qui prend un feeling manuel, bien tu ne le sauras jamais. Et tu as un phénomène de puissance et tout ça -c'est pas pareil.
32	Often enough, you’ll have home-made software and the person who uses it [first] knows what it’s for. But for people who are learning, it’s not fun to only have a textual display and enter data. To perform experimental manipulations, you have to try to make it as visual as possible because most people are visually oriented […] At least you see here [with the VPLab] that it simulates something: there’s a chronometer…	Souvent, en programmation, tu vas avoir des logiciels faits maison puis le gars qui s'en sert sait à quoi ça sert mais [pour] le gars qui veut apprendre, c'est pas le fun juste d'avoir du texte puis d'entrer des données. Quand tu fais des manipulations, il faut que t'essaies que ça soit le plus visuel possible parce que la majorité du monde son visuels. […] Au moins tu vois -ça [le logiciel] simule quelque chose : il y a un chronomètre…
33	IV: I tried the RJ and the CF18 [simulators], it was fun. Interviewer: Did you have the impression that it really represented… IV: Yes, that’s why, when I got to that question, earlier in the questionnaire, of someone who tested a jib-crane on a simulation and “ is he ready to operate the [real] jib-crane ?” I answered “yes”, because I know that a pilot with the slightest prior experience, if you [first] stick him in a simulator, he can then go on to pilot the plane with no problems whatsoever. He won’t even realize that he’s not in his simulator anymore, and that he’s in the plane instead: there’s no difference. If the simulation is well designed, then we’re happy. It’s like the nuclear power-plant [question]: no matter if it’s a nuclear power-plant which can cause a lot of damage, as long as the interface [of the simulation] is the same, there is no difference. So that’s why I trust simulation.	IV : J'ai essayé le RJ et le CF18, c'est le fun. Animateur : Est-ce que t'avais l'impression que ça représentait vraiment... IV : Oui, c'est pour ça, dans le questionnaire tantôt quand la question arrive - quelqu'un qui a testé une grue en simulation, est-ce qu'il est prêt à conduire une grue - c'est pour ça que j'ai répondu « oui ». Parce que je sais qu'un pilote d'avion - un pilot qui a le moindrement d'expérience - si tu le mets dans un simulateur, il peut aller piloter l'avion puis il y en a même pas de problème. Il ne se rendra jamais compte qu'il n'est pas dans son simulateur puis qu'il est dans l'avion : il n'y en pas de différence. Si la simulation est bien faite, on est content. C'est comme la centrale nucléaire, ça l'a beau être une central nucléaire qui peut faire bien du dommage mais si l'interface est pareil, il y en a pas de différence. Donc, c'est pour ça que, oui, je crois à la simulation
34	A simulation does not help to convince you, in the end. It shows you– “Look, I’ve programmed this thing and I can obtain the right result”. However, with [the video clip], you can’t help but believe it […] it hasn’t been rigged. It’s easier to believe that the simulation has been rigged than [to believe that the video clip has been rigged or has been tampered with]. In addition, a simulation is based on equations, so that if your equations are flawed, your simulation will give you the outcome that you expect – [this is] in contrast to a video clip which is not based on equations but rather on reality, as such…	C'est parce qu'une simulation, finalement, ça t'aide pas du tout à comprendre, à te convaincre. C'est comme on montre : "J'ai programmé ça et j'arrive au résultat et j'arrive au résultat." Alors que là, [pour la séquence vidéo] tu n'as pas le choix de le croire […] ça n'a pas été truqué. C'est plus facile à croire que la simulation a été truquée que ça. Parce qu'en plus, sur ta simulation, tu te bases sur tes équations donc si tes équations sont mauvaises, ta simulation va donner les résultats que [?t'attend?] alors que ça [la séquence vidéo], tu ne te bases sur aucunes équations, tu te bases sur la réalité en tant que telle donc tu as aucune possibilité de changer...
35	experimental error “was part of the game,” and that “students don’t learn anything from perfect labs.” The purpose of a lab experiment, he said, is also to learn about errors caused by instruments: “You learn about theory and at the same time, you learn that instruments are not perfect.”	Ça fait partie de la game. Un labo parfait, c'est un labo où t'apprends rien. Le but d'un labo c'est d'apprendre les erreurs des appareils. En même temps que tu apprends la théorie, t'apprends que les appareils ne sont pas parfaits.
36	LY: […] the video sequence can do anything,	LY : […] le vidéo fait vraiment n'importe quoi – il

	really – it does whatever you tell it to do, whereas the simulation behaves in accordance to mathematical calculations. In the case of the video sequence, you'll say: "Maybe, it was just drawn that way," whereas with the program, if in fact you are shown with disclosure what is really happening using vectors and such, it's more credible. Interviewer: OK, so a video sequence can be… LY: It can be anything. Take movies: you have special effects, etc. Well, I may be pushing it a little… You do tell yourself that your school isn't working against you, but that notwithstanding. Normally, I would have more trust in simulation – it proves more. Video shows no proof. It's like television. If you watch television, you are passive – with simulation, you can interact […] That's what we used to do in physics with MAPLE [software]: we had a model and we could change the data […] and the model would change in accordance. Then we verified this manually by calculations on the blackboard and saw that things were accurate.	fait ce que tu lui dis tandis que la simulation répond à des calculs mathématiques. Le vidéo, tu te dis : "Il l'a peut-être dessiné comme ça," tandis que le programme, si justement tu lui montres - la transparence - ce qui se passe vraiment avec les vecteurs et des choses comme ça, là c'est plus [davantage] crédible. Animateur : O.K., donc une séquence vidéo, ça peut être... LY : Ça peut être n'importe quoi : regardes les films : les effets spéciaux, etc. [il sourit]. C'est peut-être pousser un peu mais... Tu te dis que l'école n'est pas contre toi mais même là – […] Normalement, moi je ferais plus confiance à la simulation – elle démontre plus de preuve. Le vidéo montre aucune preuve. C'est comme la télévision. Si tu regardes la télévision, tu es passif; [avec] la simulation, tu peux peut-être plus interagir. […] C'est ça qu'on faisait en physique avec Maple - c'est qu'on avait notre modèle et on changeait les données [...] et il changeait selon les données qu'on donnait. Et après ça on vérifiait manuellement avec les calculs sur le tableau et on voyait que c'était pareil.
37	You can't help but be perfectly convinced when the experiment is conducted in front of your eyes. And viewing a video sequence is almost equivalent to having the experiment conducted in front of your eyes – you can't say a thing… Whereas, in the case of a computer, effects that infirm [theory] are just as programmable [as those which confirm theory].	On n'a pas le choix d'être parfaitement convaincu quand l'expérience est faite sous nos yeux. Et le fait que ça soit une séquence vidéo, ça équivaut presque à être fait sous nos yeux. On peut rien dire... Tandis que dans le cas de l'ordinateur, l'effet contraire pourrait être tout aussi simulable.
38	Interviewer: More people would be convinced by the video clip [than by the simulation] ? MZ: […] Yes. However, that may not be a positive thing. Perhaps it's an aspect of media in our time: "This really happened: look we filmed it !" – Ah yes, now I believe it. But that doesn't mean that it would be more credible objectively. I think people would be more convinced but that doesn't mean that it would be more credible… Interviewer: From a scientific point a view ? MZ: Yes, that's it: from a scientific point of view, [video] has no value.	Animateur : Il y a plus de gens qui seraient convaincu par la séquence vidéo ? MZ : […] Oui. Mais ça c'est peut-être pas positif. Ça c'est peut-être un peu l'aspect des médias... en ce moment - du genre : "C'est arrivé, regarde on l'a filmé." "Ah oui, j'y crois maintenant". Mais ça veut pas dire que objectivement, ça serait plus convaincant. Je pense que les gens seraient plus convaincus, mais ça veut pas dire que ça serait plus convaincant... Animateur : Du point de vue scientifique ? MZ : Oui, c'est ça, du point de vue scientifique, ça n'a aucune valeur.
39	Interviewer: To allow someone to develop abilities relating to manipulation [of apparatus], to [the application of a] method, to rigour, and accounting for things that can happen in a lab… AN: Well, then maybe [you could push it] further. There's one dimension that is the comprehension of concepts and another dimension that is manual experimentation. On one hand, to help you	Animateur : Pour permettre de développer des habiletés de manipulation, de méthode, de rigueur, de prise en compte des différents trucs qui peuvent se passer dans un... A.N. : Là, admettons [qu'on pourrait] aller plus loin. Tu as le volet 'compréhension d'un principe' et t'as le volet 'expérimentation manuelle'. D'un côté, pour comprendre, ça va bien mais [pour]

	understand [concepts], this is fine… but on the other hand, to personally perform experiments , then I think that a real lab is necessary. Interviewer: To help you understand , it's fine but to experiment, not really… AN: No.	expérimenter toi-même, ça, je pense -- c'est un laboratoire réel [qui est nécessaire.] Animateur : Pour comprendre, c'est assez mais pour expérimenter vraiment... A.N. : Non
40	Maybe putting it in 3D could help…	Que ça soit vraiment palpable ? Je ne sais pas... le mettre en 3D, je ne sais pas. Peut-être.
41	AN: […] air must be [acting] on it, so it [the disc] will eventually stop… Interviewer: You think it'll eventually stop ? AN: Yes [..] because the pump eliminates a certain type of friction but not all of it. Interviewer: What do you think about the fact that we still included some friction ? AN: Well, I would say it's truthful. Very realistic. Interviewer: An is that necessarily a good thing or would you say that it is not important ? AN: Yes, it's important. You have to try to get as close to reality as possible when you experiment in physics because… If you take away many real conditions, you'll end up with a theory that is applicable only within your own conditions.	AN : […] il doit y avoir de l'air là-dessus, ça fait que ça va finir par arrêter... Animateur : Tu penses que ça va finir par arrêter ? AN : Oui […]Parce que la pompe élimine une certaine forme de force de frottement, mais pas tout. Animateur : Comment trouves-tu ça qu'on ait tenu compte encore d'un certain frottement ? AN : Bien c'est très véridique, je dirais. Très réaliste. Animateur : Et ça, est-ce nécessairement une bonne chose ou tu dirais que ce n'est pas important ? AN : Si, c'est important. Il faut le plus possible se rapprocher de la réalité quand tu fais une expérience de physique puisque tu vas faire quelque chose... Si tu enlèves beaucoup de conditions de réalité, tu finis par faire une théorie qui est applicable juste dans tes conditions à toi.
42	would be the protagonist [in the simulation] exactly as they did before [in the video clip]	C'est moi qui va être l'acteur [dans la simulation], finalement, exactement comme eux l'ont fait avant [dans le clip]
43	Interviewer: When you saw the 20 centimeter marker, what did that suggest ? AN: 20 centimeters in reality [emphasizing the word "reality"]. But now, you've transposed that to your monitor.	Animateur : Quand tu as vu le 20 centimètres, ça t'a suggéré ça ? AN : 20 centimètre EN RÉALITÉ [il met de l'emphase sur ces mots.] Sauf que là, tu l'as ramené sur ton écran.
44	Because the most important obstacle for software may be that people will always think that things have been pre-arranged, like special effects in a movie. They will say: "Well they've arranged it so it's just right." So this is the advantage of having video as a complement. You can see that it hasn't been pre-arranged.	Parce que c'est peut-être la barrière la plus difficile pour un logiciel, c'est que les gens vont toujours pensé que c'est arrangé avec le gars des vues. Ils vont dire : "Ils se sont arrangé pour que ça tombe pile." Tandis que c'est l'avantage d'avoir un vidéo en complément. Tu le vois que ce n'est pas arrangé.
45	Paraphrase: saying that it was "almost identical to the real motion [the real phenomenon]." But he also said that, having worked on an air-cushion actual table, it [the VPLab] could not completely replace the actual experiment because the experience with the VPLab was far less tangible. He compared the VPLab to having a picture of	Tu vas apprécié la photo, mais tu vas apprécié sa présence. C'est un peu la même chose : tu vas apprécié travailler là-dessus [le LVP] parce que ça reproduit, c'est presque identique au vrai mouvement. Mais ayant travaillé sur une vraie table, ça ne se remplace pas. [« tangible » est la traduction de « palpable »,

	someone famous and likened performing the actual experiment to shaking that person's hand in "real life". "You may appreciate the picture," he said, "but you'll appreciate his presence [even more]".	adjectif présent dans une autre citation]
46	Well, because it's still numerical – the images are drawn or made with a computer. But if you see it… You know, if you see someone in weightlessness on television, it's not the same as actually being in weightlessness yourself.	Bien vu que c'est numérique - c'est des images déssinées ou des images faites à l'ordinateur... Tandis que si on le voit là... Tu sais, si on voit quelqu'un en apesanteur à la télévision, ce n'est pas pareil comme si on est nous-mêmes en apesanteur.
47	quite similar to the motion you would obtain on the real [apparatus]	Ça ressemble pas mal au mouvement qu'on obtiendrait sur le vrai…
48	[…] but working with units and having to take into account [zoom-levels] 100%, 200%, 400% and having to translate those [units] to centimeters – I'm not used to this. When I'm in a lab, I work in centimeters and I can't get more than a 100% [zoom-level] – I can't zoom-in on my apparatus.	Mais déjà que de travailler en unités et ramener ça à 100% , 200%, 400% ramener ça en unités, ramener ça en cm - moi je ne suis pas habituer de faire ça. Quand je suis en lab, je travaille en cm tu peux pas faire plus que du 100% ; je ne peux pas zoomer ma table de travail.
49	by installing "a system of cameras" and by disposing of "a graphical interface on a computer"	installer des systèmes de caméra en laboratoire qui filment, ensuite avoir une interface graphique sur un ordinateur
50	Then again, in physics, it's not weird to have uncertainty [in measurements]: it's experimental. So it's normal to have uncertainty: we calculate it.	Remarque que, en physique, c'est pas bizarre les incertitudes : c'est expérimental. Donc c'est normal qu'il y ait des incertitudes ; on calcul des incertitudes.
51	[…] it would be possible to reproduce it [reproduce a merry-go-round in a research lab] because we see in the video clip that they did it in Paris. It is possible to do it !	Tu sais, ça serait possible de le faire, de reproduire ça parce que tu vois dans le vidéo [la séquence vidéo dans l'esp. de présentation du LVP] qu'ils l'ont fait à Paris.
52	Interviewer: Why was " 20 cm " written on the purple marker ? DQ: Because it's the real space. And we're in a space that's… well, not virtual, but a space with a scale. So the scale would be that 1.1 centimeters is equivalent to 20 centimeters in reality. If we want to calculate, we can use this [scale] to transform…	Animateur : Pourquoi on a écrit ' 20cm ' sur le ruban mauve ? DQ : Parce que c'est l'espace réel. Puis nous, on est dans un espace... bien, pas virtuel mais c'est l'espace avec une échelle. Donc l'échelle ça serait que pour 1.1 centimètres, c'est 20 centimètres dans la réalité. Si on veut faire nos calculs, à partir de ça on peut transformer....
53	I would not have thought of that. [The VPLab] looks well built, very structured – it's going to work: nothing would go wrong.	Moi je n'y aurait pas penser. Ça l'air tout bien fait, tout structuré... d'après moi, ça va marcher, il n'y aura rien qui ne marchera pas.
54	As for realism, it is also important to have the opportunity of seeing the disc moving on an actual table, in an actual lab, because I'm not so sure that it enters into your head as much when you see it on a computer – it's not as convincing as when you see it for real.	Pour ce qui est du réalisme, c'est quand même important aussi de voir vraiment sur la table à coussin d'air, les trucs qui se déplacent de même parce que par l'ordinateur, je ne suis pas sûr que ça rentre aussi bien dans la tête ; ce n'est pas aussi convaincant en fin de compte que de le voir pour vrai. Sauf que pour ce qui est de...
55	I must admit that all the gadgets somewhat divert your attention from what you really should be doing – from the real phenomenon. It distances you a bit more from the physical phenomenon. You see it a bit like a game or a gizmo for drawing. It's more or less real and it…	Parce que j'avoue que tous les gadgets détournent un peu l'attention de ce qu'on doit faire vraiment - du vrai phénomène. Ça distance un peu encore plus du phénomène physique. Tu vois ça un peu comme un jeu ou un truc de dessin. C'est plus ou moins réel et ça te... ça

	it's distracting.	détourne ton attention.
56	I have to admit that I like this. […] I like this software – I enjoy performing physics experiments like this with instruments [like these].	J'avoue que j'aime bien ça.[…] Le logiciel – faire des expériences physiques comme ça avec des instruments. Ça me plaît.
57	ER: […]I was really expecting to measure [between] dots. In fact, it's because I was relating this to when I had done this in college – when I measured distances between dots [in college], I was not doing it through a window. I was measuring directly: the distance [measured] between two dots WAS the distance between two dots. I would not have expected to go to a [monitor]screen and to have to transpose [the measurement]. Interviewer: And now that you know, does it seem strange to work like this ? Or is it normal… ER: Well… strange […] It bothers me. Interviewer: In reference to what you've done in the past, it still bothers you ? ER: Well, it bothers me to have to do scale conversions of measurements […] it's like calculating something that does not correspond to anything real.	ER : Parce que moi je m'attendais réellement à mesurer des points. En fait, parce que je faisais pas mal référence à quand je l'avais fait au Cégep cette expérience là - je faisais la même affaire. Quand je mesurais des distances entre des points, je ne faisais pas ça par une fenêtre. Je mesurais ça directe : la distance entre deux points, c'était cette distance là entre deux points. Je me serais pas attendu à repasser par un écran puis faire une transposition. Animateur : Puis comment que tu trouves ça maintenant que tu le sais, est-ce que c'est tout de même étrange de fonctionner comme ça ? Ou c'est normal ou c'est plutôt.. ER : Bien... étrange […] Bien... ça me gosse. Animateur : Par rapport à ce que tu as fait, ça te gosse encore ? ER : Bien ça me gosse d'avoir à faire un changement d'échelle. […] c'est comme calculer quelque chose qui correspond à rien de vrai.
58	When I use these instruments, it doesn't relate to anything real. It's purely like playing a video game with a plane cockpit.	Quand j'utilise des instruments, ça fait référence à rien de réel. C'est purement comme si tu joues à un jeu d'ordinateur puis tu as le cockpit de l'avion.
59	Interviewer: Why does [the VPLab] have much potential [to allow performing physics experiments] ? FS: Well, when you watch the video clip and you watch this [simulation], both do exactly the same thing – [the simulation's designers] have included friction ; they have included most of the constraints that could be applied to it.	Animateur : Qu'est-ce qui fait qu'il [le LVP] a un gros potentiel ? FS : Bien c'est que si tu regardais le vidéo avant et que tu regardais ça [la simulation], ça faisait exactement la même affaire – ils ont mis le frottement là-dessus, ils ont mis à peu près toutes les contraintes que tu pouvais mettre dessus.
60	FS: Well I was still thinking that I would do [uncertainty assessment] approximately. Interviewer: Is it still because [the VPLab] doesn't seem serious enough to you ? FS: Well, it looks like a game… that's why. You do it quickly…	FS : Bien là je pensais encore : "je vais le faire à peu près". Animateur : Est-ce que c'est encore le fait que ça te semble pas assez sérieux ? FS : Bien, ça l'air d'un jeu, c'est pour ça [il sourit]. Tu le fais vite vite, ça l'air d'un jeu - c'est pour ça.
61	"**a nicer texture**" , as well as "**instruments**" and "**colors**" that "look more real" – may help provide "a greater impression that [the environment] was real" Of course, the nearer it gets to reality, the more you will feel part of that world. You'll forget your surroundings and you'll really concentrate on [the simulation].	admettons que tu mettais une belle texture en bois avec, quasiment des photos - ça ferait différent... peut-être que t'aurais plus l'impression que c'est vrai. Oui, c'est sur que plus ça se rapproche de la réalité, plus tu vas entrer dans le monde dans le fond. Tu vas oublier ce qui est autour et tu vas vraiment te concentrer là-dessus.
62	It's not just entering data and getting answers in return. You actually manipulate things. There is uncertainty involved. And it really emphasizes that there is a stake in error [on measurements].	Ce n'est pas juste d'entrer des données et ça te donne des réponses. Tu manipules des affaires. Tu as de l'incertitude dessus. Et ça met vraiment l'emphase sur- que t'as un jeu d'erreur.
63	approximate measure, yet still precise	mesure approximative mais quand même précise

64	Interviewer: Is it normal or strange to ask you to assess uncertainty here ? FS: No, no… That's always fine: no instrument can be 100% reliable. And furthermore, with this software, you realize that the purpose is to simulate something [so] you have some error [uncertainty].	Animateur : Est-ce que tu trouves ça bizarre ou normal que l'on te demande d'évaluer l'incertitude là-dedans ? FS : Non, non.. C'est toujours correcte. Tout instrument peut pas être sûr à 100%. Puis encore là, sur ce logiciel là, tu te rends compte que c'est pour simuler quelque chose : tu as une erreur en quelque part.
65	Interviewer: What does this [work]space represent? FS: Well it's as if the camcorder was connected to a flat video screen placed on the ground [facing upwards]. You would have your instruments there and you could work on the screen. […] It looks like a smooth screen – if this were in reality, you could put the objects [i.e. instruments] on it.	Animateur : Qu'est-ce que ça représente l'ensemble de cet espace là ? FS : Bien c'est comme si ta caméra serait connectée à un écran vidéo plat à terre. Et là tu aurais les instruments et tu pourrais jouer dessus. […] Ça l'air d'un écran lisse – si c'était en réalité, tu pourrais mettre des objets dessus [il pointe les outils].
66	Everybody is a bit like Saint-Thomas," he claimed. "You'd like to get into the machine and really launch [the disc] yourself."	Tout le monde est [comme Saint] Thomas un peu. Tu aimerais ça te mettre dans la machine et vraiment le lancer [le disque] toi-même.
67	Interviewer: What's going on ? GT: Well, when [the disc] hits one side of the table, it keeps going so I imagine – like I saw in the film [i.e. the video clip] – that [the side of the table] is like an elastic that perpetuates the motion. […] Interviewer: So why was the 20cm marker put there [in the simulation] ? GT: In my opinion, it's to give the scale of reality. Interviewer: And where is reality ? GT: Reality is what we saw in the film – the merry-go-round. […] In comparison to the film, we see that it is realistic and that 15 people can sit on the bench [in the merry-go-round], so the size [i.e. the scale] seems realistic to me.	Animateur : Qu'est-ce qui se passe ? GT : Bon, quand il [le disque] percute un mur, il continue donc j'imagine que - comme j'avais vu dans le film [la séquence vidéo] - c'est comme une bande élastique qui perpétue le mouvement. […] Animateur : Donc, le [marqueur de] 20 centimètres, pourquoi il a été mis là ? GT : C'est justement. D'après moi, c'est pour donner l'échelle de la réalité. Animateur : La réalité, où est-elle ? GT : La réalité, c'est ce qu'on a vu dans le film - l'espèce de manège.[…] Comparé au film, on peut voir que c'est réaliste et qu'il y a une quinzaine de personnes qui peuvent s'asseoir sur les bancs, comme ils disaient - c'est ça 15 personnes -donc, ça me semble une grandeur réaliste.
68	[…] the object [the disc] may not move at the same speed or… I really have to tell you that it will never be the same ; the object will never move like the real one even if it starts at the same position, [and you launch it] with the same force. Given that the computer does not account for everything that happens in reality, I would not obtain the same [experimental] results at the end. It may be close, though. But you will never have [exactly] the same results. So you would have three types of results: the theoretical result [i.e. prediction] shared by all, the result obtained with [the VPLab] and the result that you really would get in reality.	[…] ton objet se déplacera peut-être pas à la même vitesse ou... C'est sûr, il faut vraiment que... je veux vraiment te dire que ça sera jamais pareille; ton objet ira jamais vraiment comme le vrai - même si tu le parts à la même place, à la même force, vu que ton ordinateur ne tient pas tout ce qui se passe en réalité en ligne de compte, j'aurais pas les même résultats à la fin. Peut-être que ça va se rapprocher par exemple. Mais tu n'auras pas les mêmes résultats. Donc tu aurais trois sortes de résultats : le résultat théorique que tout le monde va avoir, le résultat que tu as avec ça [il pointe l'écran] et le résultat que tu as vraiment en réalité.
69	it was good to include possibilities for errors on measurements when "simulating a real experiment"– absent that, he said, "experimental results would be practically the same as theoretical results [i.e. predictions].."	Vu qu'il essaie de reproduire la réalité, il n'est pas comme un ordinateur qui va me donner exactement [la quantité voulue]. Parce que là, c'est sûr que les résultats théoriques vont être pratiquement la même chose que les résultats pratiques si tu étais capable de 'snapper' – d'avoir la vraie distance.

		Dans ce cadre là d'une expérience réelle, oui c'est bon.
70	A computer is perfect. When you activate the air-cushion pump, it's precise. The pump produces constant pressure. So this is data that will be more precise on a computer than in reality. The computer does not account for all, all, all of what is in reality so it's certain that your results will be almost perfect compared to reality.	C'est parfait un ordinateur. Quand tu parts ta pompe, c'est précis. Ta pompe, elle, te donne une pression constante. Donc ça c'est une donnée que tu vas avoir - en plus sur un ordinateur plus précis que dans la réalité. Ton ordinateur ne tient pas compte de tout, tout, tout ce qu'il y a en réalité donc c'est sûr que ça va être presque parfait tes réponses comparées à la réalité.
71	So we say that experimental reality cannot get close to theoretical simulation.	On dit que la réalité ne peut pas approcher la simulation théorique.
72	This is good. It's a lot like real results. I think it's a good way [to do things] on a computer because in reality you don't need to record since you're there, you see, you handle [apparatus], and you collect your results at that time.	C'est bon. Ça ressemble pas mal à un résultat réel. Je pense que c'est une bonne manière sur un ordinateur parce que réellement [dans la réalité], tu n'as pas besoin d'enregistrement parce que tu es là, tu vois, tu manipules, tu prends les résultats en même temps.
73	did not know how the ruler worked	Je ne sais toujours pas comment la règle fonctionne.
74	It's like when you look at a design drawing, working for a firm. They tell you not to measure on the drawing even if it is scaled – no ! – really because this lacks precision. But here we're talking about physical experiment. That's why my point of view is changing a bit because I've been thinking too much in terms of components production…	C'est comme quand on regarde un dessin en entreprise, ils nous disent de ne pas mesurer dessus même si tu pouvais faire l'échelle - NON ! - c'est justement à cause du manque d'un manque de précision. Mais là, on parle d'une expérience physique. C'est pour ça que mon point de vue change un peu parce que je suis trop dans le point de vue Production...
75	[…] because in reality, I would have trouble measuring distances between instant 1 and instant 2 [i.e. at different time indexes]. I would almost have to stop the camera – pause the camera – and determine a path on the television screen, and then roughly assess its length.	[…] parce que moi, en réalité j'aurais de la misère en mesurer les distances entre un tel nombre de moment [de temps] et [un autre] tel nombre de moment. Il faudrait quasiment que j'arrête la caméra - que je fasse des pauses sur la caméra - et que je détermine à l'écran de la télévision, un sillage et que je détermine à peu près c'est quoi la longueur de ça.
76	Driving a real car and driving a car simulator do not provide the same feeling.	Conduire une vraie voiture ou conduire un simulateur de voiture, c'est pas le même feeling.
77	HU: I feel more at ease when taking measurements [in an actual lab] ; you can take the sheet [of carbon paper] and work directly on it without having to factor in a [scale] ratio. Interviewer: It's having to factor in the scale ratio that… HU: Well, not necessarily. It's just faster [in an actual lab]… there's no zoom […] With [the VPLab], the concept is good except that you have to go through two or three steps in order to obtain one measurement. Interviewer: The manipulations themselves are more fastidious ? HU: Yes, a bit. Here, I measured three distances and it took me some time to do so, whereas, had I been in a lab, it could have taken me only one minute… On the other hand, it couldn't have been	HU : Je me sens plus à l'aise pour mesurer [...] [en labo] on peut prendre la feuille et travailler directement sur la feuille, on n'a pas à tenir compte d'un ratio. Animateur : C'est le fait de tenir compte d'un ratio qui ? HU : Bien pas nécessairement, c'est juste le fait que ça mesure plus vite... il n'y a pas de zoom. […] Ça ici [avec le LVP] le concept est bon, sauf qu'il faut que tu fasses deux ou trois étapes pour pouvoir mesurer. Animateur : La manipulation comme telle, pour mesurer est plus fastidieuse ? HU : Oui un petit peu. Comme là, j'ai mesurer trois distances et ça m'a pris un bout de temps tandis que - avoir été dans un labo, ça peut prendre 1 min... Quoique le concept [du LVP]... ça ne peut

	any faster [on a computer]. I don't see a way of making it faster [on a computer].	pas être bien bien plus rapide que ça. Je ne vois pas aucune manière que ça pourrait être plus vite que ça [sur un ordinateur].
78	I always think that it's experimental so [the procedure] can't be computer-driven ; we have to do things ourselves.	Je pense toujours que c'est expérimental donc il ne faut pas que ça soit informatique, il faut que ça soit nous autres vraiment qui fassent les choses.
79	Interviewer: What do you think about assessing uncertainty with software, in an environment like this one ? Do you think it's normal ? HU: Yes, it's normal. What I like about this, is that it's the same as in a lab: it's nothing less, nothing more. In a lab, you can forgo assessing uncertainty, if you so desire – you're free – you can forget about it if you want. There is nothing to tell you: "Here, you have a column [in your notebook] to note uncertainty." [Instead:] "I give you a blank notebook and you do what you want with the columns. You write what you want at the top."	Animateur : Qu'est-ce que tu penses de calculer les incertitudes dans un environnement comme ça, dans un logiciel comme ça ? Est-ce que tu trouves ça normal ? HU : Oui, c'est normal. Moi ce que j'aime de ça, c'est que c'est pareil comme ça se passe en laboratoire, c'est rien de plus, c'est rien de moins. En laboratoire, tu peux ne pas prendre les incertitudes si tu veux - t'es libre - tu peux les oublier si tu veux. Il n'y a rien qui te dis : t'as une colonne [dans le cahier] ici là pour l'incertitude. "Moi je te donne un cahier de note qui est blanc et tu fais ce que tu veux avec les colonnes, tu écris ce que tu veux en haut..."
80	It's good because we see that the disk is somewhat slowing down. Because having absolutely no friction is impossible.	C'est quand même bon parce qu'on voit que la rondelle a un certain ralentissement [le disque a ralenti un peu]. Parce que ça ne se peut pas un frottement qui est zéro, zéro, zéro [un frottement nul], ça ne se peut pas.
81	If it is intentional, it must be replicated because there's a reason [for it]… but my impression is that if they were to construct another merry-go-round and wanted to do away with the vibrations, they would manage it. However, I think it's good to produce a simulation which represents, as much as possible, what it's like to really do the experiment. If you look at real flight simulators, they include wind turbulence ; [for] a race car simulator, it's the condition of tires and adherence to the road… it's good to account for as many things as possible.	Si c'est voulu, il faut le reproduire parce qu'il y a une raison ... mais j'ai l'impression que s'ils ont à refaire un autre manège comme ça [au palais de la découverte] et ils ne veulent pas de vibrations, ils vont s'arranger pour qu'il n'y en ait pas. Mais je trouve ça bien de produire une simulation qui représente le plus possible ce que c'est de vraiment faire l'expérience. Moi c'est sur qu'une simulation c'est de reproduire le plus possible la réalité. Je regarde les vrais simulateurs de vol, ils vont tenir compte du vent des turbulences, ou un simulateur de course, c'est la condition des pneus et l'adhérence... c'est bon de tenir compte d'autant de choses que possible.
82	In a simulator," he said "the same thing could happen maybe but, well… you do a RESET and you start over	Dans un simulateur, ça pourrait peut-être faire la même chose mais, bon tu fais un RESET puis tu recommences.
83	"reflected" "was faithful to an experimentation" "I can measure and do the same steps"	Ça reflète Fidèle à une expérimentation Je peux mesurer puis retrouver les mêmes étapes
84	I would expect that the faster [the merry-go-round] goes, the more [the disc] should move about but that's not what they said in the video clip, so it's normal that it doesn't do this.	Si je ralentis [le manège...] je m'attendrais à plus je vais vite, plus qu'il se déplace mais ce n'est pas ça qu'ils disaient dans la présentation donc c'est normal que ça fasse pas ça.
85	IV: […] when they introduced the simulation [in the video-clip], there was a man there [beside the air-cushion table]. But now [in the simulation], nobody's there. So I imagine that if I'm the man, I have to be there and bring the disc […] Interviewer: Does it give you the impression that	IV : quand on présente la simulation, il y a un petit bonhomme ici [elle pointe à droite de la table]. Là, il n'y a rien. Donc là j'imagine que si moi, je suis le petit bonhomme en question, il faut que je me place ici [elle pointe à droite de la table].Donc j'approcherais ça [elle approche le disque du côté

	you are the man [in the video clip] or is it... IV: Well, I'm looking to do the experimentation but as I saw in the video clip, it was the man who initiated the [disc's] motion. Because if I start the pump and do nothing else, nothing happens. However, if I start the pump and I give [the disc] a little push, it is going to start moving.	droit de la table…] Animateur : Est-ce que tu ça te donne l'impression que tu es le petit bonhomme en question ou tu cherches plutôt ? IV : Bien je cherche à faire l'expérience mais comme je voyais dans la présentation, c'est le monsieur qui actionnait le mouvement. Parce que si je parts la pompe [elle part la pompe] mais que je fais aucun mouvement [elle ne fait pas de manipulation du disque], il ne se passe rien. Toutefois, si je parts la pompe et que je donne un petit élan [elle lance le disque lentement], ça va se déplacer.
86	IV: Uh… there's no friction – of course, there is always… [The disc] should always keep moving slightly. It should not stop that much or [it should only stop] after a very, very long time. Interviewer: Would you say that there is uncertainty as to the presence of friction ? Would you say that presently, you are not sure whether friction exists or not [on the table] ? IV: Yes… Well no, but I know that in real life, it is impossible to have [a surface] with absolutely no friction. It is logical that this [simulation] should account for that. But the uncertainty comes from me – by which I mean: what happens if there's friction and what happens if there isn't any? It's me and not the software. Interviewer: If there wasn't any friction… IV: If there wasn't any, [the disc] would always keep moving slightly and it would continue the motion it was given. Interviewer: And, if there was friction [on the table] ? IV: Eventually, it would stop. Interviewer: What do you observe at this moment ? IV: I observe that [the simulation] is representing a situation where [the disc] really tends to stop eventually, so I think that there is a tiny bit of friction somewhere. To conclude, I think that reality is well represented by this.	IV : Là... euh, il n'y a pas de frottement - c'est sur il va toujours y avoir.... [elle fait une grimace et semble incertaine]. Il devrait toujours continuer à bouger un peu. Il ne devrait pas arrêter tant que ça, ou [il devrait arrêter] après un très très très long temps. Animateur : Pour toi, est-ce qu'il y a une incertitude quant au frottement ? Est-ce que tu dirais que présentement, tu n'es pas certaine s'il y a un frottement ou... IV : Oui...Bien non mais je le sais que dans la vie, ça ne se peut pas quelque chose qui n'a absolument aucun frottement. Que ça [la simulation] le représente, c'est logique. Mais, l'incertitude du au frottement vient de moi. Dans le sens où qu'est-ce que ça fait s'il y a du frottement ou s'il n'y en a pas ? C'est plus ça l'incertitude. C'est plus moi que le logiciel en question. Animateur : S'il n'y avait pas de frottement... IV : S'il n'y en avait pas, ça continuerait toujours à bouger un petit peu puis ça continuerait toujours à faire le mouvement qu'on lui a imprégné. Animateur : S'il y en avait ? IV : Éventuellement, ça arrêterait. Animateur : Et présentement ce que tu remarques... IV : Ce que je remarque, c'est que ça représente le fait que ça tend vraiment à arrêter éventuellement donc, il y a un mini frottement quelconque. Je pense que ça représente bien la réalité - si je fais une conclusion.
87	logical if one wanted to make a true simulation that represented reality	si on veut faire une vraie simulation et représenter la réalité, c'est logique que ça [le ruban] arrête à me moment donné.
88	I have the impression of looking at… by analogy, it's as if I was looking at an oscilloscope and I could take measurements directly on the screen. […] It gives me the impression that I could be in front of a screen which, I hope, would be very flat […]	j'ai l'impression d'être devant... bien comme si j'étais devant, par analogie, un oscilloscope où je pourrais aller prendre des mesures directement sur l'écran. […] Ça me donne l'impression que je pourrais aller devant un écran qui serait, j'espère, très plat [elle rapproche ses mains de l'écran et éloigne sa main droite de sa main gauche comme si elle tenait un galon ou une règle] et que je pourrais mesurer ce que j'ai à mesurer.

89	[…] it isn't reality which is inside [the computer], because that with which you feed the computer is the stuff of theory.	[…] là-dedans [l'ordinateur], le réel n'est pas là parce que ce avec quoi tu le nourris ton ordinateur pour générer ton expérience, c'est du théorique.
90	[…] if it looked real, I think that people would believe it more – I would believe it more. But it's still a computer […] For example, if I were in a virtual reality where time dilation [a concept in the theory of relativity] would be demonstrated, maybe I would be more inclined to believe it in there [as opposed to with the VPLab], simply because it would have the sensation of being more real. At the same time, though, I could tell myself: "Yes, but this is a computer, so…"	[…] si ça avait l'air vrai, je pense que les gens croiraient plus, que je croirais plus mais c'est vraiment un ordinateur aussi. […] Mais par exemple si j'étais dans une réalité virtuelle et que quelque chose montrait qu'en effet, il y a une dilatation du temps, peut-être que je serais plus porté à le croire comme ça [avec la RV] que comme ça [elle pointe l'écran], simplement parce que ça la sensation d'être plus vrai quand c'est comme ça [avec le casque]. Mais en même temps, je pourrais me dire : "Oui mais c'est l'ordinateur donc..."
91	[…] it truly is like reality, for if the air-cushion was perfect – really ideal – then [the disk] would keep on going forever. This, however, gives you a taste of how things really happen.	[…] c'est vraiment comme la réalité. Parce que si le coussin d'air était parfait - vraiment idéal - alors ça [le mouvement du disque] continuerait toujours. Mais là, ça donne un goût de comment ça se passe vraiment.
92	sometimes things are not so pretty [in reality]	Il va falloir qu'il sache qu'il y a des fois où les choses ne sont pas si jolies.
93	KX: You can have errors in a lab, but here [in the VPLab] you have nothing – it's simulated: there is no source of randomness which comes into play. In a lab, you learn to be precise, but here all you have to do is… that is, unless errors of randomness appear [in the simulation]. Interviewer: Is it possible, or is it plausible that these errors exist [in the VPLab] ? KX: Well, I don't know if they've been programmed. Interviewer: Is that something you would normally expect, or on contrary not at all ? KX: No, because later you have to find out why the randomness [i.e. the error] has occurred and that would be a bit complicated, as opposed to a a lab where you can always say: "Yeah, I know, I launched [the disc] incorrectly… etc." […] It's more complex [in an actual lab]. Here [in the VPLab], you have a limited number of variables which can come into play […] you can't simulate reality perfectly. So, I think that it would be much better in a lab.	KX : Tu peux aussi avoir des erreurs dans un laboratoire alors qu'ici, tu n'as rien, c'est simulé : il n'y a aucune source de hasard qui entre en jeu. Dans un labo, tu apprends à être précis alors qu'ici tu n'as juste qu'à - tout est simulé, à moins qu'il y ait des erreurs de hasards qui apparaissent là... Animateur : Est-ce que c'est possible ou est-ce que c'est plausible qu'il y en ait ? KX : Bien, je ne sais pas si elles ont été programmées. Animateur : Est-ce que ça serait quelque chose à laquelle tu t'attendrais habituellement ou pas du tout ? KX : Non, parce que après, trouver pourquoi le hasard a eu lieu, ça serait un peu compliqué tandis que dans un labo tu peux toujours dire : "Oui, je sais, j'ai mal lancé... et tout", etc. […] Bien c'est parce que c'est plus complexe. Parce que là tu as un nombre limité de variables qui peuvent entrer en jeu tandis que dans un labo réel, tout entre en ligne de compte. C'est beaucoup plus une situation réelle que [celle qui est] simulée parce que tu ne peux pas simuler parfaitement la réalité. Alors, je crois que ça serait beaucoup mieux en lab.
94	[…] if it is previously indicated that this is truly a model of a real situation, including those types of errors, then [such a simulation] would be very good in fact.	[…] si c'est indiqué que c'est vraiment une modélisation d'une situation réelle, y compris des erreurs comme ça, là ça serait bien. Ça serait, en fait, vraiment bien.
95	an environment where conditions are perfectly controlled	ton environnement est parfaitement contrôlé
96	That's just it: with a computer, theoretically you	Parce que justement, avec un ordinateur, tu es

	can enjoy much more precision than in a real experiment so it seems to me that [the VPLab] should take advantage of this a little.	capable d'être théoriquement beaucoup plus précis qu'avec une vraie expérience donc il me semble que ça [il pointe l'ordinateur] devrait faire ressortir ça un peu.
97	Interviewer: Does it seem either normal or strange that we should ask you to evaluate uncertainty in this case ? More or less normal ? KX: Uh… It's quite normal since the [tape measure's] ring makes it imprecise enough. Absent that, I would find it a bit strange given that with a computer you can [usually] obtain as much precision as you desire. Unless the context is such that one of the objectives of the lab report is to perform statistical analysis.	Animateur : Est-ce que ça te paraît normal ou étrange qu'on te demande de calculer l'incertitude dans ce cas-là - ou plus ou moins normal ? KX : Euh... Non, c'est quand même assez normal comme c'est assez imprécis à cause de l'anneau. Mais s'il n'y avait pas d'anneau, je trouverais ça un peu étrange comme on peut être aussi précis qu'on veut avec un ordinateur, sauf dans le cadre où le but du rapport, c'est aussi de faire de l'analyse statistique.
98	board that presents results in an animated way	c'est juste un tableau de résultats finalement mais c'est animé
99	I converted it using the scale – I converted it to real life centimeters.	Je l'ai convertie avec l'échelle - je l'ai convertie en centimètres, dans la vie réelle
100	I think it has good potential. Small improvements could be made – I could easily give it 3 or 4, say 3,5 [on a 5-point scale, with 4 signifying: high potential].	Je trouve qu'il a un bon potentiel. Selon - il y aurait peut-être des petites améliorations - ça pourrait être facilement 3 ou 4. Trois point cinq [3.5].
101	Obvious things should be given. Things that you have to learn [in an actual lab] should be learned [in the virtual lab], but you shouldn't have to learn to measure with a tape measure.	Les choses évidentes devraient être données. Les choses qu'il faut apprendre, on les apprend mais mesurer avec un tape tu n'apprends pas ça...
102	totally react [according] to theory	réagit totalement à la théorie
103	I expect that [the simulation] would take into account all physical factors involved – when you do an experiment, you take all physical factors into account, except if it is specified from the start that [including a given factor] would exceed the experiment's objectives [i.e. that it would not be useful to attain its objectives…] This is just being honest with the student […] if you tell him, he understands that something which goes on [in reality] is not represented [by the simulation] because it exceeds the course's content or something like that…	Je m'attends à ce que ça tienne compte de tous les facteurs physiques ; quand tu fais une expérimentation, tu tiens compte de tous les facteurs physiques, sauf si c'est dit vraiment au début, que ça dépasse les compétences de l'expériences : telle chose, telle chose, telle chose […] c'est être honnête avec la personne. […] si tu lui dis, elle comprend que c'est peut-être pas au programme sauf qu'il y a quelque chose qui se passe pareil qui n'est pas représenté parce que ça dépasse le contenu ou quelque chose comme ça...
104	I think that this is perfect given that it would be used for an introductory course. I imagine that it would be clearly written, etc. In my opinion, you don't expect more than this – this is what you expect. Anyway, when you do an introductory lab experiment like this, there are some things that you neglect. The teacher says: "Neglect this type of friction or this other thing". For sure, it won't be perfect there either. You expect that too. It rounds off. It's just to show you that it tends towards what theory predicts – you don't see perfect theory.	Moi je trouve ça parfait [il pointe l'écran] compte tenu des limitations que ça va être un cours d'introduction. J'imagine que ça va être bien écrit, etc. Tu ne t'attends pas à plus, tu t'attends à ça d'après moi. De toute façon, quand tu fais un laboratoire comme ça d'introduction, comme je disais, il y des choses que tu négliges. Le prof. dit : "Bon bien néglige tel frottement ou telle chose". C'est sûr que ça ne sera pas parfait là non plus. Tu t'attends à ça aussi. Ça arrondis en gros. C'est juste pour montrer que ça tend vers la théorie sans avoir la théorie parfaite.
105	It's normal: you always have to assess uncertainty on all measurements, with all instruments.	C'est normal : il faut tout le temps que tu évalues l'incertitude sur tout tes appareils, toutes tes mesures
106	I find that making measurements on a television	Faire des mesures sur un écran de télévision dans

	screen, in a simple case like this one, is… well, it's artificial. I can't imagine circumstances where this could be advantageous compared to leaving a trace [on carbon paper]. […] I would tend to say that the approach itself does not seem realistic: to film a sequence so you can later make measurements as on a video image… it's a bit gadgety… However, I imagine it's hard to do otherwise on a computer.	un cas simple comme ça [l'expérience en question], je trouve ça ... bien c'est artificiel. Je ne vois pas dans quelle occasion ça serait avantageux de faire ça plutôt que de laisser tracer.... [sur un papier carbone] […] J'aurais tendance à dire que la démarche elle-même n'a pas l'air réaliste : le fait de filmer une séquence pour ensuite aller mesurer comme sur l'image vidéo .... oui... ça fait un peu gadget... je ne le sais pas... mais en même temps c'est difficile de faire autrement à l'ordinateur j'imagine.
107	I wouldn't say it is futile, because you always have to deal with uncertainty. I would say that it is artificial. Uncertainty [in the VPLab] is induced by poor resolution of the image. Well…you do have to introduce uncertainty somewhere…	Je ne dirais pas que c'est futile, parce qu'il faut toujours tenir compte de l'incertitude. Je dirais que c'est artificiel. Que l'incertitude est un peu provoquée par la mauvaise résolution de l'image. Bon [en haussant les épaules] c'est sur qu'il faut introduire une incertitude en quelque part là...
108	MZ: My results would be way off, even considering experimental uncertainty ? Interviewer: Yes. Maybe that has happened to you in the past ? MZ: Yes. But in this case, I would tend to say that it would still be my fault. Even if this is software, I would not think that it is the simulation's fault – all in all, the laws of physics pertaining to this are simple enough. I would trust it.	MZ : Je suis loin de la prédiction même compte tenu des incertitudes ? Animateur : Oui. Ça t'es peut-être déjà arrivé ? MZ : Oui. J'aurais tendance à dire même dans ce cas là que c'est de ma faute quand même. Même si c'est un programme, je ne croirais pas que c'est la faute de la simulation. Somme toute, les lois de la physique là dedans sont assez simples. J'aurais quand même confiance en ce qui me donne.