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# Grounding Concept in Percept: Learning Physics Experientially in Multi-user Virtual Worlds

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## Abstract

*Despite almost 25 years of research related to "misconceptions" in science education, students today still widely hold erroneous beliefs about natural phenomena and continue to engage in intuitive forms of pseudo-scientific reasoning. In this paper, we stress the importance of grounding concept in percept when students engage learning. We appeal to Kolb's experiential learning theory to guide the design of C–VISions, a collaborative learning environment that provides experientially grounded learning. We report partial results from an empirical study of three students learning kinematics in C–VISions, presenting some quantitative as well as qualitative findings. We discuss our findings in relation to the pervasive misconception referred to in the literature as "V-F reasoning." We conclude by pointing to ongoing research to develop pedagogical agent support in C–VISions to complete the conception of experiential learning advocated here.*

## 1. Introduction

Research related to student "misconceptions" in science education has a history of 25 years or more. The seminal paper by Viennot [1] on spontaneous reasoning in elementary dynamics marked the beginning of active research related to students' intuitive beliefs and their understanding of the physical world (see [2], [3]). A consistent finding of early research is that students possess a causal understanding of physical phenomena that is at odds with scientific knowledge.

Viennot [1] argues that "we all share a common explanatory scheme of 'intuitive physics' which, although we were not taught it at school, represents a common and self-consistent stock of concepts and which, however wrong it may be, resists attempts to change or modify it" (p. 205). Because this explanatory scheme does not conform to a Newtonian account of physics, it is widely described as arising from "misconceptions." This term, however, is unnecessarily judgmental and carries an implicit (usually Newtonian) frame of reference [4]. We will therefore use the more neutral term "preconceptions" in the rest of this paper.

It is important to appreciate that physics represents a "learned" view of the world. It is a scientific construction of the world. It is often not natural. (Consider, for example, the construct of a "ray of light.") Physics deals with complex reality by proposing pertinent simplifications, extracting from this complexity certain factors that it considers as decisive and measurable. In doing so, it seeks to establish itself as a serious competitor to natural thought through its superior coherence and predictive power. Given that nature does not directly suggest what one should study in a phenomenon in order to understand it, are natural reasoning and scientific reasoning incommensurate? Adherents to this viewpoint call for concept displacement and paradigm shifts in students' understandings. Hence, common school teaching employs declarative methods such as saying, showing, illustrating, and emphasizing. However, these approaches have very limited impact.

Rather than treat common beliefs and intuitive reasoning as being, in some sense, "wrong" or inferior, we advocate an approach to learning that we characterize as "from learning *that* to seeing as" (where the verb "see" is used in a constructive sense). In our research, therefore, we seek to help students internalize scientific thinking by grounding the Newtonian concepts in percept and experience of phenomena so as to make these concepts more concrete and intuitive. In pursuit of this goal, our research effort spans two major logical parts. The first is to design and develop a virtual world learning environment where students can experience physics-related phenomena (in a virtual world sense) and discuss the causes underlying the experienced phenomena with collaborating peers. The second part is to design and develop pedagogical agent support in the virtual worlds to provide cognitive as well as metacognitive scaffolding for the students' collaborative learning process. In this paper, we report results from our study of student learning based on use of the system developed in the first part.

In the next section, we outline Kolb's theory of experiential learning and explain how it serves as the pedagogical foundation for the design of C–VISions, our virtual world learning environment. We then describe some key features of C–VISions. Next, we describe an empirical study of students learning in the virtual world environment and present some quantitative and qualitative findings. We discuss our findings in relation to existing literature on "V-F reasoning" before concluding the paper and pointing to future work.

## 2. Grounding learning in experience

Kolb's theory of experiential learning has been acknowledged as providing the missing link between theory and practice, between abstract generalization and the concrete instance, and between the affective and cognitive domains [5]. Unlike other cognitive and rationalist learning theories that tend to emphasize the acquisition, manipulation, and recall of abstract symbols, Kolb's theory proposes a holistic, integrative perspective on the learning process, combining experience, perception, cognition, and behavior of students as they learn. The theory recognizes that to learn involves the integrated functioning of the total organism including thinking, feeling, perceiving, and behaving.

Kolb's [5] model of experiential learning comprises a four-stage cycle with four adaptive learning modes: concrete experience, reflective observation, abstract conceptualization, and active experimentation. These modes comprise two basic structural dimensions of the learning process. The first is the abstract/concrete dialectic of prehension, representing two different and opposed processes of taking hold of experience in the world, either through reliance on conceptual interpretation and symbolic representation, a process called comprehension, or through reliance on the tangible, felt qualities of immediate experience, a process called *apprehension*. The second dimension is the active/reflective dialectic representing two opposed ways of transforming that grasp of experience, either through internal reflection, a process called *intension*, or through that of active external manipulation of the external world, a process called *extension*.

Importantly, Kolb's model succeeds in integrating the role of personal meaning making through the dialectic of action and reflection. Central to the concept of praxis is the process of "naming the world," which is both active—in the sense that naming something transforms it—as well as reflective—in that our choice of words *gives meaning* to the world around us. This process of naming the world and constructing meaning is accomplished through dialog among equals via a joint process of learning and inquiry [5].

Consistent with the notion of having a "dialog among equals," our learning environment design allows students to learn collaboratively through joint sense making dialog.

## 3. The C–VISions learning environment

The C–VISions learning environment is modeled as an interconnected virtual environment. In this paper, we focus on the Physics World, an environment that houses experiential interactive simulations related to learning physics. Presently, there are three virtual worlds in this environment: the Vacuum Chamber that deals with free-fall linear motion, the Battleship World that deals with non-linear motion trajectories, and the Billiard World that deals with the conservation of momentum principle. (Refer to the URL in the next paragraph for screen snapshots of the virtual worlds.) The Battleship World contains a parallel simulation that involves getting a truck to jump over a gorge successfully with the aid of a ramp.

C–VISions users are represented as avatars within the virtual environment. They can navigate within a virtual world using the navigation buttons shown in the virtual world browser. Users can teleport between different worlds. They can manipulate and interact with virtual world objects using direct manipulation techniques. User actions on objects trigger "events" (such as the truck speeding over the ramp) which can be visualized by clicking on the event visualizer button. This button brings up a separate window that allows users to replay the last triggered event and to view this event in relation to pertinent graphs (eg. object velocity against time). An object inspector-cum-editor allows students to examine and modify the properties of an object (eg. its mass). Student-to-student communication takes place either through a text chat or audio chat tool. A more complete description of the C–VISions environment can be found in [6] and at the following URL, http://www.comp.nus.edu.sg/~cheeys/cvisions.html.

## 4. The research study

An empirical research study was conducted to investigate learning processes and outcomes when students learn using the C–VISions environment. The study was conducted with three University undergraduates who had recently completed their second year of study. It spanned a period of six hours during the day, inclusive of a one-hour lunch break. The procedure for the study was as follows. Students were first asked to complete the Force Concept

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Inventory [7], a standardized set of test questions designed to assess student understanding of basic concepts in Newtonian mechanics. They were given a maximum of 29 minutes to complete the 29 questions in the inventory. Following this, the students were given a 20-minute training session on how to use the C–VISions environment. They were then given the five problems (on paper) presented in the Battleship World and requested to write down their personal answers to the problems. The first collaborative problem solving session based on this world then followed. Upon its completion, the five problems were re-presented (on paper) and the students were again asked to write down their (possibly modified) answers. During the problem solving session, students adhered to the following procedure: first, they used the text chat tool to express and share their individual answer, with justification, to each problem; next, they explored the simulation problem online to test whether their answer (or whose answer, as the case may be) was correct. When one or more answers were incorrect, students engaged in further simulation manipulation and testing, accompanied by ongoing collaborative sense making dialog, to reach consensus on a solution consistent with the way events took place in the simulation. On reaching a consensus, students summarized their understanding of their joint solution and justified their answer via the text chat tool.

After the lunch break, students repeated the foregoing procedure, but with respect to the Vacuum Chamber virtual world. Following this, the Force Concept Inventory (FCI) was administered a second time. The set of problem questions as well as the FCI were administered twice to allow identification of pre- vs. post-intervention differences in students' physics understanding. Finally, a post-study questionnaire was administered to gather feedback on the students' perception of their learning experience.

# 5. Research findings

In this section, we present two types of results: a global quantitative analysis of pre- vs. post FCI scores and a qualitative analysis of conceptual understanding based on two fragments of learning conversation. These findings represent only a portion of our total data and findings. A lack of space precludes the inclusion of more data.

## 5.1. Quantitative analysis of FCI scores

Figure 1 summarizes students' pre-test and post test FCI scores. Two students achieved percentage gains of 17% and 14% (based on a 100% total). One student turned in an identical score, but the errors on the two tests were not identical.

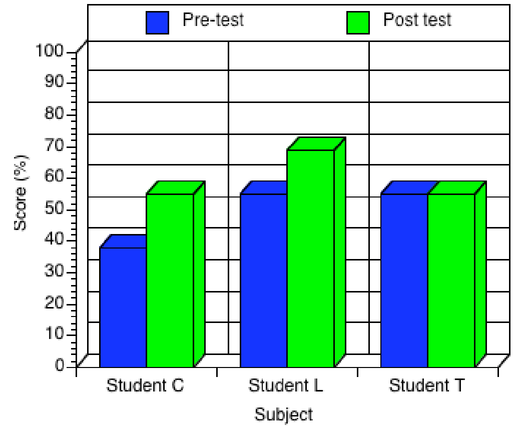


**Figure 1. FCI pre- vs. post test scores**

## 5.2. Qualitative analysis of conceptual understanding

The analysis and interpretation of conversation is always a difficult enterprise. In this paper, we focus on two excerpts from the conversation related to Problems 3 and 4. These excerpts provide a sense of the difficulty that students (even bright undergraduates) experience when trying to provide causal explanations for their predictions of the behavior of objects traveling in a projectile trajectory. They also illustrate how the students engaged in the sense making process and came to some consensus on the reasons underlying the observed behavior. Problems 3 and 4 bring together the concepts of velocity, force, and motion, concepts that are deeply intertwined in untutored, naïve reasoning. We first present the problems.

*Problem 3*: Two trucks, one considerably heavier than the other, attempt to jump over the gorge. Assuming that both trucks have the same launch velocity, which truck will travel the greatest horizontal distance from the launch point? Explain why.

*Problem 4*: Two canon balls, one having a mass of 2 kg and another having a mass of 15 kg, are fired from a canon with a fixed force F and a constant angle of elevation $\alpha$. (a) Will the shape of the trajectories of the canon balls be the same? Why? (b) Will the horizontal distance traveled by the cannon balls be the same? Why?

Before commencing problem solving in the C–VISions environment, two students, L and T, stated (on paper) in response to Problem 3 that the lighter truck would travel further than the heavier one. Student C first wrote the same response; he then cancelled it and stated that the two trucks would travel the same (horizontal) distance. When the students tested out their hypotheses with a light truck and a heavy truck and used the event visualizer tool to determine the distance traveled by the truck, they found it to be identical in both situations.

Amid the puzzled confusion that followed, the following conversation took place. (Numerals in

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parantheses on the left side are time stamps. Ellipses indicate deleted irrelevant lines. "Adm" refers to the administrator. Indented lines reflect a parallel thread of conversation.)

(11:56:20) L: i said that the heavy truck would go a shorter distance
(11:56:22) C: its the velocity that matters
(11:56:27) L: fair enough
. . .
(11:56:44) T: so why is it so?>
(11:56:46) C: its common sense
. . .
(11:56:52) Adm: Q says same launch velocity
(11:56:53) L: common sense again?
(11:57:5) L: was it the same launch velocity?
(11:57:21) T: why is it that 1 lighter, 1 heavier have about same horizontal distance?
. . .
(11:57:48) T: so there's no relationship between weight of truck and horizontal distance?
(11:57:59) L: apparently not man
(11:58:1) C: no i suppose
(11:58:5) T: so relationship involves: 1) velocity, 2)angle, 3)gravity
(11:58:12) L:     and no weight
. . .
(11:58:20) L:     but doesn't gravity affect weight?
(11:58:24) C:     gravity being constant
(11:58:27) L: no wait, that's different
(11:58:57) L: don't forget distance, that's the other half of the equation
(11:59:12) L: velocity, angle, gravity equals distance
(11:59:21) L: so can we move on?
(11:59:25) C: no
. . .
(12:0:10) C: can we think something simpler?
(12:0:15) T: if both light and heavy trucks have same launch velocity
(12:0:28) T: what is velocity's relation to Force?
(12:0:30) T: F=ma
(12:0:32) Adm: it appears that mass of truck does not affect dist traveled. How come?
(12:0:50) C: same velocity here means different force
(12:1:0) T: yeah
(12:1:8) L: yeah that's right, but what's the difference
(12:1:32) C: different amount of force needed to move the different weights

In the problem solving for Problem 4, the following conversation took place:

(12:37:8) T: so if the truck's mass doesn't affect distance traveled [ie. trucks' *different* mass in Problem 3]
. . .
(12:37:23) T: why does mass of cannon ball affect horizontal distance travelled
(12:37:38) T: what is diff between truck and cannon ball?
(12:37:49) C: same force applying to different mass has different velocity,
(12:37:51) T: i mean the truck and cannon ball experiments?
(12:37:53) L:     air resistance?
(12:38:11) Adm:     air resistance is ignored in this environment
(12:38:21) C: for canon ball, same force; for truck, same velocity
(12:38:30) T: hmm
(12:38:35) L: true true
(12:38:46) T: so we can say force affects distance travelled?
(12:38:52) L: that's what i meant when i said the question confuses force and velocity

The above excerpts make reference to concepts such as velocity, force, mass, angle of elevation, weight, and air resistance. These concepts appeared to be part of a tangled web in the students' minds. The central puzzle that students were wrestling with revolved around the fact that in Problem 3, the initial *launch velocity* was the same, while in Problem 4, the initial *force* was the same. In the former case, the distance traveled by the truck was the same, but in the latter case it was different. The juxtaposition of these two questions "forced" students to consider the comparative causal effects of velocity and force. We discuss this data further in the next section.

## 6. Discussion

The first conversation excerpt (case of same launch velocity) reveals student L expressing his expectation that the heavier truck would travel a shorter horizontal distance (11:56:20) and student T wondering why heavier and lighter truck both travel the same horizontal distance (11:57:21). Furthermore, they expressed the belief that horizontal distance traveled was independent of weight, a construct that relates mass to gravity (11:58:12 ff.). Student T then asked the critical question, "What is velocity's relation to force?" The key conceptual issue that the students seemed to be wrestling with appear to be the relationship between velocity, force, and mass. Student C, who surprisingly performed worst on the FCI tests, seemed to possess a better sense of how to understand the phenomenon when he asserted that velocity was what really mattered (11:56:22) and later pointed out that the same launch velocity for the two trucks with different mass implied that the force applied had to be different (12:0:50 and 12:1:32). Despite this insight, however, when the students worked on Problem 4 (case of same initial force), the same confusion arose concerning why the canon balls of different mass now traveled a *different* distance (12:37:23). Once again, it was student C who directed attention back to the fact that "same force applying to different mass has different velocity." In this manner, he highlighted the key difference between Problems 3 and 4 (12:38:21) and provided a way to reconcile the different outcomes observed in the two problems.

The above episodes reveal how students tend *not* to distinguish between the causal effects of same initial velocity and same initial force, treating them almost as equivalents. This finding is similar to Viennot's [5] observation that students often comment that "if the velocities are different, then the forces are different," as if velocity and force shared a linear relation. This relation is expressed as $\mathbf{F} = a\mathbf{v}$ and referred to as a "V-F response" which can be traced to the "supply of force" preconception. This preconception is based on the notion of "force of the mass" (a notion that derives from pre-Galilean impetus theory) and arises when students adopt a *global* perspective of an object's motion with spatio-temporal delocalization. Viennot's studies show that students in secondary school and university often answer as if there is a direct relationship between velocity and force rather than acceleration and force (although they know very well non-qualitatively that the relationship between force and acceleration is $F=ma$) [1]. In sum, we found that our students experienced a similar confusion between the concepts (and effects) of force and velocity.

In this first formal empirical evaluation of learning processes and outcomes with C–VISions, we were mindful that student interaction time was limited and that students could only leverage off the knowledge and understanding of each other to "level up" their collective degree of understanding. Despite these limitations, we are encouraged that the students were mostly able to demonstrate some degree of improvement both in quantitative as well as qualitative terms. Due to the small number of students who participated in the study, we cannot, at this point, draw any generalized conclusions.

Notwithstanding, we believe that our initial efforts are a step forward to helping students to ground concepts in (virtual) reality. Despite all three students finding that the learning experience was demanding and cognitively effortful (as evidenced by attributing the cause of phenomena to "common sense"), they greatly appreciated being able to test out their predictions and, in the words of one student, to "see thing happen." Because of this, they found the learning experience stimulating. The feedback from another student read: "The most exciting part about using the system was the fact that the discussion was freely done, without much interference from the instructor. This stimulated the learning process, as learning from other learners can sometimes prove enlightening . . . The virtual reality environment also produced some strong cognitive dissonance when the seen results did not correspond with intuition, this intense emotion led to a much better understanding of that physical law." These reactions appear to support taking a more experientially grounded and phenomenological approach to promoting student learning.

## 7. Conclusion

In this paper, we highlighted the continuing and widespread difficulty students encounter in learning science and, particularly, with learning Newtonian mechanics. We believe that teaching that begins and remains entirely at the conceptual level is bound to be weak and incomplete because concept is not grounded in percept. We therefore advocated Kolb's experiential learning cycle as a framework for the design of our learning environment, C–VISions. This framework provides a holistic and integrative approach to designing for learning by encompassing both the active apprehension and reflective comprehension aspects of the learning process. We then briefly described the C–VISions environment and presented some findings indicating positive quantitative and qualitative effects.

As previously indicated, C–VISions is incomplete in its current form. The second part of our research project entails the development of multiple embodied agents to provide scaffolding support needed by students. This research work has commenced. As advocated by Viennot [1], we must help students to explicitly recognize the conflict between intuitive reasoning and scientific reasoning; then, we must assist them in resolving those conflicts and settling into an alternative, experientially grounded world view. Viennot found that students who achieved a clearer view of their own thoughts demonstrated a very real measure of intrinsic satisfaction. This fact continues to motivate and drive our research efforts.

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