

# Mr. Vetro, a Collective Simulation Cyberlearning Infrastructure for Science Education

*Andri Ioannidou and Alexander Repenning, AgentSheets Inc., Boulder, CO*

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## **Abstract**

The comprehension of interdependent complex systems, which is part of state and national standards, is an enormous challenge for learners. In traditional physiology teaching materials, which structure the human body into decoupled subsystems (e.g., respiratory and cardiovascular) isolated in separate chapters, there is a ubiquitous absence of explanations for how systems *interact*. These interactions, central to understanding how the human body works, have been largely ignored because of the inadequacy of traditional teaching media. *Collective Simulations* address this by creating an immersive inquiry-science learning environment that lets students collaboratively *experience* system interactions.

## **Keywords**

Collaborative simulations, collective simulations, cyberlearning infrastructure, inquiry science, high school science, interdependent complex systems.

## **Theoretical Framework: Collective Simulations**

The Collective Simulations framework integrates *distributed simulation technical frameworks* with *social learning pedagogical models*. Fundamentally, a Collective Simulation is a cyberlearning (National Science Foundation, Task force on Cyberlearning, 2008) supported role-playing activity in which a group of people learns about complex systems, such as the human body, by discussing relationships, making decisions and experiencing interactions through a real-time simulation process.

Collective Simulations are based on the C<sup>5</sup> technology infrastructure for **C**ollective, **C**ompact, **C**onnected, **C**ontinuous, and **C**ustomizable simulations (Repenning & Ioannidou, 2005). This framework both allows and actively encourages meaningful learning (Michael, 2001) by supporting discovery-oriented social learning processes. It creates immersive inquiry-based learning, which enables radically different classroom learning experiences that engage students and teachers simultaneously.

## **Technology: Mr. Vetro**

We have implemented a prototype of Collective Simulations, called Mr. Vetro (Figure 1) and have evaluated it in local high schools. With Mr. Vetro students can learn about physiology through technology-enhanced role-play. Human systems or organs are simulated on wirelessly connected computers, while a central simulation integrates parameters into a composite representation of the human body. Organs get distributed to groups of students. One group gets the heart, another the lungs, a third controls Mr. Vetro's activity and profile. The lung group can vary parameters such as breathing rate and tidal volume in response to changing conditions such as exercise or smoking. The heart group can vary parameters such as heart rate and stroke volume. Another group controls Mr. Vetro's physical condition and exercise intensity. Calculated physiological variables, such as oxygen saturation, oxygen needed and delivered, are projected to the entire group to visualize the consequences of local decisions. Changes to input parameters immediately update the central simulation visually and audibly. Messages from Mr. Vetro and his doctor interpret the situation and convey further information to students about Mr. Vetro's current condition. The system employs sophisticated real-time visualizations, using our unique Agent Warp Engine (Repenning & Ioannidou, 2008) and auditory stimuli providing immersive experiences to learners. A modular architecture supports easy addition of new organs, input/output parameters, and equations for establishing relationships between them.

The role-play aspect makes students collaborate to deal with specific goals. For instance, a group of students makes Mr. Vetro exercise. The system does not compensate automatically, like the human body would. Instead, the other participants (heart and lungs) are forced to cope with the increased need for O<sub>2</sub> in the muscles. This leads to scientific discourse between the "organs" to agree on adjusting parameters to maintain homeostasis.

The comprehension of interdependent complex systems (Epstein and Axtell 1996; Simon 1981) is a big challenge to learners. After reviewing physiology teaching materials at middle, high school, and university levels, including textbooks, interactive CD-ROMs, and Web-based resources and titles offered by major publishers, we found a ubiquitous absence of explanations for how systems interact. These materials structured the human body into decoupled subsystems (e.g., respiratory and circulatory) isolated in separate chapters or animations with little, if any, connection. These neglected interactions are central to understanding how the human body works. Indeed, the general need to comprehend interactive systems is part of current national and state educational standards (National Research Council 1996; Thompson and Celva 2005). Realizing the need for more rigorous instruction about the interactions of systems instead of each system in isolation, many medical schools have changed or are in the process of changing their curricula to reflect a more integrated systems approach. However, this kind of change has largely been ignored at the K-12 level because of limitations of traditional teaching media. Collective Simulations can address this problem by creating an immersive learning environment that lets students collaboratively experience system interactions. These same interactive system concepts apply not only to physiology, but to other domains such as economics, ecology, and biology.



**Figure 1. Mr. Vetro Collective Simulation: Students control organs (heart, lungs) distributed on wirelessly connected computers. The central simulation projects the entire human being, calculated vital signs, and a blood-centric representation of the body for the entire group to see. Mr. Vetro and his doctor communicate the situation (e.g., hyperventilation) via messages. The teacher acts as discourse facilitator.**

## **Content and Curriculum**

Collective simulation technology alone does not produce effective education. The content with which students interact with has to be authentic and should be delivered using carefully designed activities. Our Collective Simulations are embedded in comprehensive curriculum material—including lesson plans, student worksheets, teacher material, off-computer activities, and evaluation material. To develop content and curriculum based on our philosophy of inquiry-based, self-directed science that is relevant to students, the technical team collaborated with medical experts who provided the physiological expertise behind the simulation; educational experts from the University of Colorado School of Education who developed pedagogical approaches to implement and evaluate Collective Simulations; and science teachers who wrote lesson plans and designed activities to integrate simulations into teaching practices.

The resulting educational materials included a complete cardiopulmonary unit that covered aspects of the normal physiology of the circulatory and respiratory systems, exercise physiology as it relates to the cardiopulmonary system, and scenarios of abnormal states of the system due to situations such as substance abuse. One of our main objectives for this unit and essential question we wanted the students to explore was understanding how smoking and exercise affects the cardiopulmonary system. In activities using the Mr. Vetro Collective Simulation, students compared an average person with a sedentary smoker and an elite athlete. We wanted students completing this unit to be able to explain what it means to “be in shape” in terms of the heart, lungs, and blood cells and to be able to articulate what the physiological difference is between an athlete and a “couch potato.” By using Mr. Vetro for these activities, students discovered typical values for the heart rate, breathing rate, stroke volume, and tidal volume of the three Mr. Vetros (average, elite athlete, sedentary smoker). Students also simulated Mr. Vetro exercising and discovered his anaerobic threshold and how to keep him in the aerobic range while exercising. We also integrated math into the activities by asking students to predict and collect data from the simulation for the three Mr. Vetros then graph and interpret their data.

## **Significance: Evaluation Outcomes**

The Collective Simulations framework with the Mr. Vetro prototype and curriculum was evaluated by educational and assessment experts at the University of Colorado, School of Education. The curriculum was developed and adapted for classroom use in collaboration with local science teachers. The evaluation study occurred in three local high schools. Five science teachers participated: two teaching only using Mr. Vetro (treatment); two teaching only in their conventional way (comparison), and one teaching both using Mr. Vetro and in the conventional way. A total of fifteen science classes (Biology, AP Biology, Anatomy and Physiology, and IB Biology) participated. About 400 high school students, ages 14-18, were part of those classes. The evaluation study results were successful along educational and pragmatic dimensions.

## **Educational Outcomes**

In our evaluation studies with Mr. Vetro, both learners and teachers benefit from Collective Simulations.

- **Teaching:** Teacher practice results provide compelling evidence that the instructional practices and learning experiences provided in the Mr. Vetro class were more conducive to promoting scientific inquiry and student learning of concepts. Teaching performance was

measured by the Reformed Teacher Observation Protocol (RTOP; Piburn et al., 2000), which is designed to document characteristics of classroom practice that define reformed teaching by measuring five related constructs of inquiry-oriented teaching (Lesson Design and Implementation; Propositional Knowledge; Procedural Knowledge; Communicative Interactions; and Student-Teacher Relationships). In our experiment, we found that teacher performance increased in all categories in the Mr. Vetro classes compared to the comparison classes (Luhn, 2010).

- **Learning:** learning outcomes were measured with Measured with pre- and post- assessments modeled after the Programme for International Student Assessment (PISA) by the Organization for Economic Co-Operation and Development (OECD) and other standardized tests. These assessments were designed to elicit students' knowledge and ability to apply knowledge using tasks on three levels: Level I were geared toward recalling basic facts, Level II involved making connections, and Level III required application of knowledge in new situations. Mr Vetro results in stronger learning gains in Level I and Level II questions for all groups. Level III questions, which require critical thinking and deeper knowledge of physiological phenomena and the responses of human systems in scenarios that students were not explicitly taught, were significantly more complex in the Mr. Vetro groups than those in the matched comparison groups (Keyser, 2010).
- **Engagement and transfer:** Collective Simulations engage students in new ways. Interestingly, self-reported motivational data shows that less advanced students get more engaged and interested in science than advanced placement students, regardless of the strong learning gains (Webb, 2010). Teachers report seeing a lot more interaction among all students than they usually see, and they attribute it to the content and the fact that each student has a role in the activity. They also report application of the knowledge gained in subsequent activities in their biology classes:

*"[Students have a better understanding of how the circulatory and respiratory systems work together] because the other day we did an outbreak scenario and the disease was malaria but the patients had some symptoms and they didn't use the word "hypoxia" [a term used in Mr. Vetro], but the kids did. And they talked about what the heart rate was in the scenario and they were talking about it in terms of Mr. Vetro and what they had learned, which I think was really cool! Somebody learned something and they were applying it to a whole different scenario!"*

– high school science teacher

## Pragmatic Outcomes

Some of the most exciting results are the real-life consequences that impact students at a personal level, as the quotes from students and teachers below indicate. For us, the fact that there are indications that the experiences with Mr. Vetro promote self-awareness (e.g. understanding personal health issues) and healthier life styles (e.g. deciding to quit smoking) is non-trivial, but instead, some of the most revealing and exciting results of this project.

"I have a bunch of lung issues, and I never really got what my doctor was telling me, and now all of a sudden I get it!"

– high school student

"I have one student who wants to quit smoking - she was asking how to go about doing it, because that [the Mr. Vetro experience] encouraged her. Her mom emailed me and was so excited - nothing else ever touched her daughter to stop smoking. This is what did it!"

– high school science teacher

## **Conclusions**

The results from our formal evaluation studies of using the Mr. Vetro collective simulation demonstrate a positive impact on scientific inquiry, student learning, and students' interest in personal health issues. It is particularly encouraging that this technology can address the lack of scientific understanding that goes beyond academics and is essential to everyday life. Low health literacy, that is, the struggle of people obtaining, processing, and understanding basic health information, is a fundamental problem for the entire society. Our experiences indicate that Mr. Vetro promotes understanding regarding smoking, substance abuse, and the need for exercise among high school students.

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