WIIS: Multimodal Simulation for Exploring the World beyond Visual Sense

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Abstract

This paper describes a pilot study of a computer simulation called WIIS, which is designed to extend students' learning experience of the sizes of the objects beyond human vision. By interacting with a simulation that incorporates temporal, aural, and visual representation (TAVR), students are expected to refine their mental model of the sizes of the objects too small to see with human eyes (called submacroscopic objects). The goals of the study are to explore whether middle school students can understand TAVR in a simulation and how they use their experience of interacting with TAVRs to refine their mental model of the sizes of submacroscopic objects.

Keywords

Learning technologies, multimodal representations, simulations

ACM Classification Keywords

H.5.1 Multimedia Information Systems, K.3.1 Computer uses in education

Introduction

Nanoscience is a domain where learners can greatly benefit from using a learning technology because the phenomena at nanoscale are beyond the visual sense. In fact, many students have difficulty in conceptualizing the basic concept of nanosicence – how small are the objects that are too small to see. Prior research shows that students tend to think all objects that are too small to be seen with the naked eye are roughly the same size, even similar with small macroscopic objects such

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as a grain of rice [9]. Research on the mental model of size comparison [3] and students' conception of sizes [9] imply that the absence of direct visual experience of an object is the main reason that such misconceptions develop.

A number of learning technologies have been developed to address this challenge by adopting various representations such as video (e.g., Powers of Ten [5]) or interactive visual representations (e.g., Scale Ladder [8]). In such technologies that offer alternative visual experience of submacroscopic objects, the visual representations of submacroscopic objects are enlarged to a visible scale or they grow as a student interacts with them. Also, in many cases students are requested to visualize how small such objects are through proportional reasoning using the numbers presented in the representations (e.g., "the diameter of a Rhinovirus is about 40,000 times smaller than one millimeter").

However, prior research indicates that frequent exposure to the macroscopic visual representations of submacroscopic objects seems to cause students to overestimate the sizes of the objects [9]. Some students even tend to think that the size of the visual representation of a submacroscopic object is the actual size of the object [9]. This observation implies that visual representations may not always be useful when one cannot have direct visual experience of the target object. Also, research (see [9]) implies that visualizing the sizes of submacroscopic objects via proportional reasoning is likely to be beyond students' cognitive capacity.

1 mm (millimeter) = 10^{-3} *m*
1 µm (micrometer) = 10^{-6} *m*
1 nm (nanometer) = 10^{-9} *m*

These challenges in the use of visual representations and proportional reasoning raises a need for learning support that may provide learners with an alternative way of thinking about the sizes of submacroscopic objects and consequently refine their mental model of such knowledge. The theories of "intellectual partnership [7]" between tools and individuals and "distributed cognition [2]" suggest that technologies can enhance or transform the ways humans think and the knowledge that humans construct. Moreover, a representation that directs learners to explore the concepts in a different way may help them realize and revise their misconceptions [1].

To address this issue, we designed *Wow, It Is Small!* (WIIS), a Flash-based learning environment where students can explore the sizes of submcroscopic objects by interacting with multimodal simulation that incorporates temporal, aural, and visual representations.

Wow, It Is Small! (WIIS)

WIIS is composed of a set of temporal-aural-visual representations (TAVR) for different submacroscopic object (see Figure 3 for selected objects) and an interface to support learners' sense making.

Temporal-aural-visual representation (TAVR)

A TAVR simulates the sequential placement of a submacroscopic object across the head of a pin (1 mm in diameter). When a user presses the simulation's "Play" button, one object is placed on the head of a pin every 0.1 seconds, subsequent objects are placed next to the previous ones. This sequential accumulation of a submacroscopic object is continued until the objects are fully lined up across the pinhead. When one object is

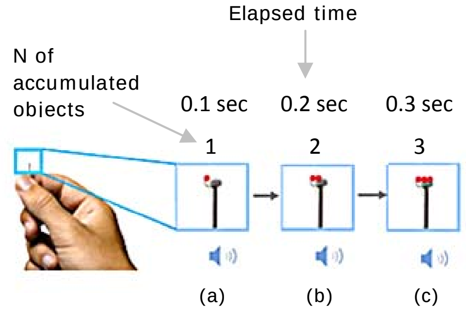


Figure 1. An illustration of the accumulation in TAVR.

(a) The first submacroscopic object is placed on the pinhead, and one click is played.

(b) The second object is placed on the pinhead next to the first one, and one click is played.

(c) The process continues until the object spans the pinhead.

placed on the pinhead, a single audio click is played. See Figure 1 for an illustration in TAVR.

The temporal aspect of the representation is the time it takes for the object to span across the pinhead. The goal is to use temporal aspect to give the learners a sense of the object's size. The aural representation (i.e., the click) and the visual representations (i.e., accumulated objects indicated as red dots) are the modalities used to convey the accumulation of objects on the pinhead. We chose these modalities based on the dual coding theory [4] that explains information is processed through two separate but parallel channels - visual and auditory. Because of the problem tied with the macroscopic depictions of submacrosopic objects, visual representations are added only when the accumulation enters the macroscopic scale. Thus, the accumulation of objects in the submacroscopic scale is represented via the duration of sound. The sizes of submacroscopic objects are represented by the inverse relationship between the size and the duration of sequential object placement. The smaller the object, the more objects are required to span the pinhead.

WIIS – A TAVR Simulation

We designed *Wow, It Is Small!* (WIIS), a Flash-based learning environment where students can interact with TAVRs for selected submacroscopic objects. The goal is to support students in making sense of size (see Figure 2), following the scaffolding work in Quintana et al. [6]. Students can directly manipulate various TAVRs in drag-and-drop fashion to order the represented objects by size while interacting with TAVRs. In WIIS, the largest units of the accumulation time of the selected sample submacroscopic objects match with the scale category they belong to (see Figure 3). For example, it takes several seconds for microscopic objects, hours for nanoscopic objects, and days for sub-nanoscopic objects.

Pilot study

We investigated how student interaction with TAVR influenced their mental model of the sizes of the submacroscopic objects. We also examined whether students could understand TAVRs.

Participants

Eleven 7th grade students from a local private school volunteered for this study. A researcher met with each student individually in their science classroom for about forty minutes after school. A laptop computer with WIIS, computer mouse, and microphone were provided to them.

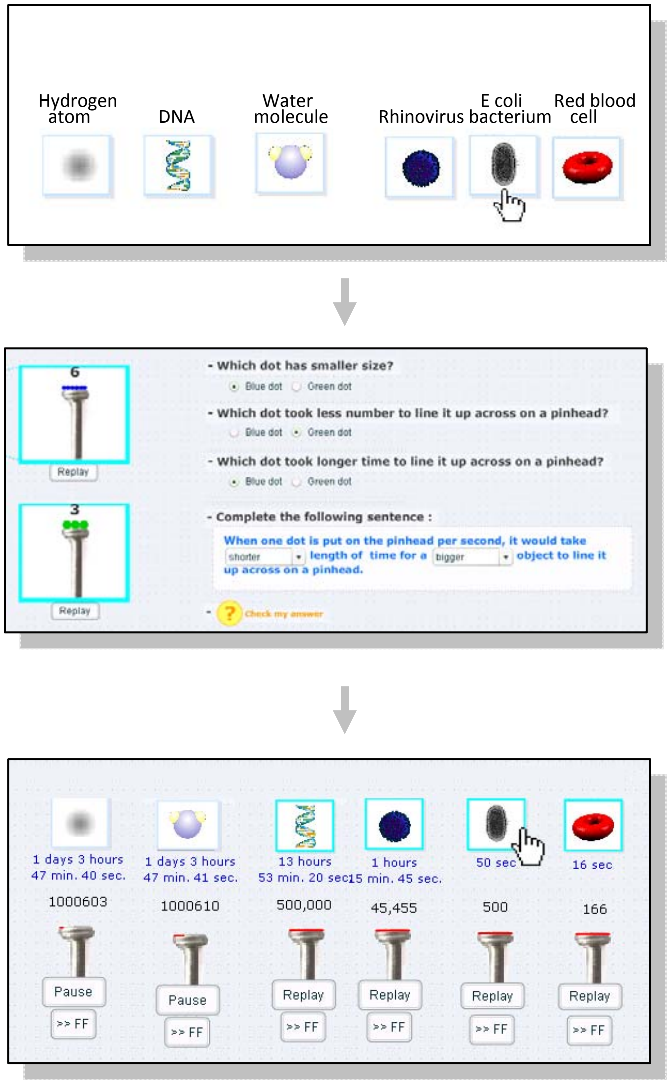
Data collection

Prior to giving tasks to the students, we assessed the participant' preexisting knowledge about size (Phase 1 in Figure 2). The focus of questions included: (1) whether they had basic idea of what the sample submacroscopic objects were, and (2) the knowledge they had about the sizes of the objects. To examine whether the students could understand what TAVR represents, we asked them a set of interview questions after they explored the sample TAVRs (Phase 2 in Figure 2). The questionnaire was developed to investigate whether the students could understand: (1) that one click represents one object placed on a pinhead, (2) that there exists only sound until the accumulation becomes macroscopic, and (3) the inverse relationship between the time it takes for an object to span the pinhead and the size of the object. To observe the students' mental model of the

Phase 1.
Students order the objects from the smallest to biggest depending on their preexisting knowledge.

Phase 2.
Students play sample TAVRs and solve quizzes to check their understanding of what TAVR simulates.

Phase 3.
Students explore the sizes of submacroscopic objects by interacting with TAVRs created for the objects. Students can revise their initial object ordering from Phase 1.



- Which dot has smaller size?
● Blue dot ○ Green dot
- Which dot took less number to line it up across on a pinhead?
○ Blue dot ● Green dot
- Which dot took longer time to line it up across on a pinhead?
● Blue dot ○ Green dot
- Complete the following sentence :
When one dot is put on the pinhead per second, it would take shorter length of time for a bigger object to line it up across on a pinhead.
- Check my answer

Figure 2. Three phases of learning activity in WIIS.

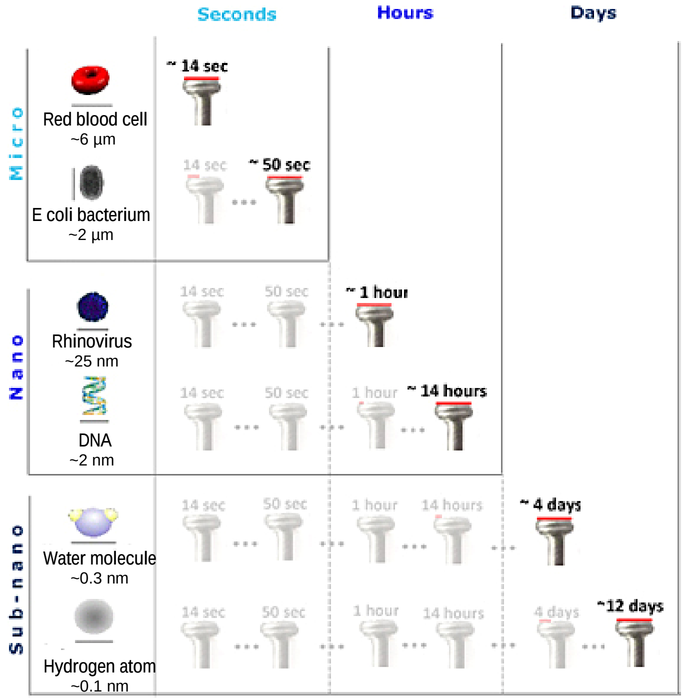


Figure 3. The sizes and the duration of accumulation for the submacroscopic objects used in this study

submacroscopic object size changes over time, students were asked to order the objects from the smallest to the largest before they began exploring the sizes of the objects in WIIS (Phase 1 in Figure 2). After they interacted with the TAVRs for each sample object (Phase 3 in Figure 2), they were told to revise their initial ordering based on the experience with WIIS.

Further, to investigate how the students used the temporal component of TAVR to refine their mental model of submacroscopic object size, we asked them to make predictions of the time it takes for an object to span the pinhead and reflect upon the difference between their prediction and the actual result. Students represented their reflections by editing the drawings of the objects and marking on seven-point bipolar Likert scale that ranged between “extremely smaller than I thought”, “similar with what I thought”, and “extremely bigger than I thought.” As hints for making predictions, students used a TAVR with hair diameter as the represented object. The thickness of hair is almost the smallest size that human can see with the naked eye (~100 micrometer). The students’ interaction with WIIS shown in the computer screen and their verbal responses were recorded by using screen recording software. Coding rubrics about the students’ object ordering and justifications were developed to analyze the data.

Results and Discussions

All participants showed the evidence of understanding what TAVRs represent in their answers. This implies that such a simulation and the inverse relationship between the time it takes for an object to span the pinhead and the size of the object may not be difficult concepts for middle school students to understand.

During the interview exploring their preexisting knowledge, we noticed that all of the students had a basic idea of what the objects were and that they are too small to see with human eyes. However, they only had rough idea about the sizes of the objects such as “atom is the building block of everything, so it must be the smallest.” The ordering and grouping of the objects by all students were incorrect except for an atom, and their justifications were mostly based on misconceptions.

However, the students’ representations of their conception of the sizes of the submacroscopic objects after Phase 3 showed that WIIS was useful for them in refining their mental models. All participants correctly sorted the objects by size using the temporal information given in the TAVRs. The ratio of the revisions students made to the drawings of the objects was consistent with the amount of the difference between their prediction and the result. For example, when their prediction was shorter than the actual result only by a few seconds, they made smaller changes in their drawings than to the drawings of the objects that their predictions were off by more than several hours.

In the seven point bipolar Likert scale, nine participants stated that all of the given submacroscopic objects turned out to be smaller than they thought. Other two students answered that the sizes of red blood cell was similar with what they thought and the rest of the objects were smaller than they thought. In their explanation of the logic behind the reflection: (1) all students actively used the difference between their prediction and the actual result to respond to the Likert scale question, (2) the responses in the scale were consistent with the difference between the prediction and result they noticed, and (3) their responses in the scale was consistent with the severity of difference between the prediction and result. For example, a student who predicted that it would take less than one hour for an atom to span the pinhead (it takes about 12 days) answered that the size of an atom was “extremely smaller than I thought” in the scale. The same student responded that the size of a red blood cell was similar with what he thought because his prediction was 10 seconds (it takes about 14 seconds for a red blood cell). This consistency in the justification was noticed in all participants' responses.

Future Work

We are developing a second version of WIIS that refines the interface and explores a more diverse collection of representation. We also want to develop a version that contains a larger number of submacroscopic objects that a teacher or students can select from. We are planning to conduct experimental research that compares the effectiveness of WIIS with other learning technologies that are designed for same learning goal, but depend on visual representations.

Conclusion

We have presented a simulation that incorporates temporal-aural-visual representations to support learners exploring the sizes of the submacroscopic objects. The findings imply that middle school students can understand what TAVRs represent and that a multimodal simulation could be useful for learners to refine their mental model about the size of objects beyond direct experience. While this study is important for the designers of learning technologies, we believe it also has further implications for HCI. It points to the potential role of a non-typical modality in expanding our experience of the world. It also shows that interaction with a novel form of technology can alter the ways people think about an abstract concept and consequently improves the comprehension of the new information.

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