TAVR: Temporal-aural-visual Representation for Representing Imperceptible Spatial Information

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Abstract
Designing a technology tool to support learners better conceptualize the imperceptible scale has been a challenging research topic for learning technology researchers. Because of the limits in human visual sense and cognitive capacity, visual representations have not been successful in representing such scales. To address this issue, I designed a computer-based simulation that incorporates a multimodal (temporal-aural-visual) representation (TAVR). In my dissertation I assess the successfulness of TAVR and potential design options.

Keywords
Learning technologies, temporal modality, multimedia tools, multimodal representations.

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

General Terms
Design, Experimentation

Introduction
'Size and Scale' is one of the core concepts in mathematics and science. However, many students have difficulty in conceptualizing the scale that is too small to see (submacroscopic). A number of learning technologies have been developed to address this challenge by adopting different forms of visual representations such as video (e.g., Powers of Ten) or interactive visual representations (e.g., Scale Ladder). Such learning technologies convey the submacroscopic sizes by providing alternative visual experience of the sizes of the submacroscopic objects (e.g., the objects are enlarged to a visible scale or they grow as a student interacts with them).

However, prior research on people's scale conception and spatial cognition indicate that learners face cognitive challenges in interpreting such visual representations of imperceptible scales. For example, some students tend to equate the sizes of the objects

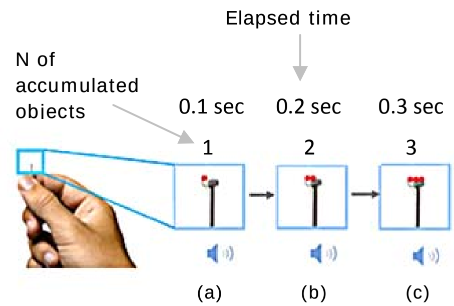

Figure 1. An illustration of the accumulation in TAVR.

(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.

Figure 2. A screen capture of WIIS.

that are too small to see with the sizes of small macroscopic objects such as a grain of rice [7]. The visual representations that are unreal in terms of sizes are hard to be the replacements for the direct visual experiences; rather, it generates misconceptions in students.

External representations co-determine the very nature of the human cognitive task, and the interaction with them may enhance and transform human cognition [3, 8, 9]. A well-designed external representation may allow a learner understand a concept that would have been beyond his or her cognitive capability. Moreover, an external representation that directs learners to explore the concepts in a different way help them realize and revise their misconceptions [2]. In this regard, a novel form of representation that alters the way they think about the submacroscopic sizes may help them better conceptualize such sizes by changing the nature of the cognitive task that they have to deal with.

Temporal-aural-visual Representation

I designed TAVR to alter the way learners think about the submacroscopic sizes. A TAVR simulates 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 placed on the pinhead, a single audio click is played. See Figure 1 for an illustration of the accumulation in TAVR.

The temporal aspect of the representation is the time it takes for the object to span across the pinhead. 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. I chose these modalities based on the dual coding theory [5] that explains that information is processed through two separate but parallel channels - visual and auditory. Because of the problem tied to 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. Therefore, the smaller the object, the more objects are required to span the pinhead.

I hypothesize that time can be a good modality for representing imperceptible spatial information for the following reasons. First, our mental representations of the things that we can never see or touch may be built, in part, out of representations of perception and action that happens over a certain period of time [1, 7]. Second, the units of time (e.g., second, minute, hour) can become conceptual metaphors of scale categories. Analogically extending the conceptual structure from richer, experience-based domains (the units of time) may structure learners' understanding of relatively more abstract domains (the imperceptible sizes) [1].

Application: Wow, It Is Small! (WIIS)

I designed Wow, It Is Small! (WIIS), a Flash-based learning environment where students can interact with

TAVRs of the selected submacroscopic objects. In WIIS, the largest units of the accumulation time of the objects match with the scale category they belong to (see Figure 3).

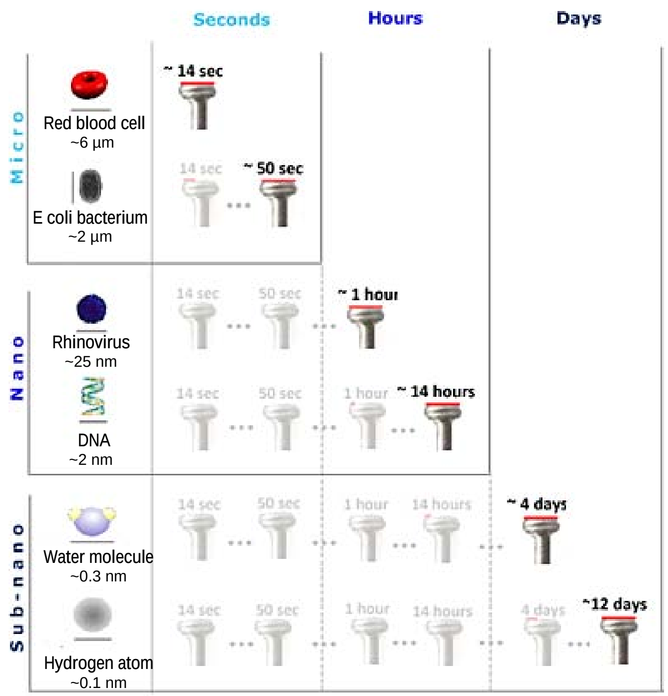

Figure 3. The sizes and the duration of accumulation for the submacroscopic objects used in this study.

Prior Work: TAVR Assessment

Norman [4] stated that a successful representation: (1) is appropriate for the person, (2) captures important features of the represented world, and (3) is appropriate for the cognitive task. Upon this framework, I conducted observations, interviews, and surveys with eighty middle school students.

I found that the middle school 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 [6]. All participants correctly sorted the objects by size using the temporal information given in the TAVRs. The temporal aspect of TAVR was useful for guiding students to recognize the vast differences in the sizes of submacroscopic objects [6]. Although there did not exist strong unanimity in the ways the students interpreted the relative differences between the durations, it was clear that time was a meaningful concept for learners that they can analogically build further understanding of an abstract concept upon.

Remaining Work

First I plan to conduct an experimental study that compares the effectiveness of WIIS with other learning technologies that are designed for the same learning goal, but depend on visual representations, to experimentally verify the effectiveness of TAVR for representing imperceptible spatial information.

Second, I will investigate what components of TAVR contribute to the successful TAVR interaction. TAVR is composed of three different modalities – temporal, aural, and visual. To inform to the community of interface designers who may be interested in using time as a main modality to represent abstract spatial information, I plan to conduct an experimental study that explores the different effects with different combinations of each modality (see Table 1). The assessments for both first and second study will include software logs of user behavior, pre-and post-tests of content knowledge, surveys and interviews to obtain affective feedback, and video records (with dialogue analysis) to study user interactions. The collected data will be statistically analyzed (qualitative data will be quantified according to coding rubrics).

	Temporal	**aural**	**visual**
Treatment 1	O	O	O
Treatment 2	O	O	X
Treatment 3	O	X	X
Treatment 4	O	X	O
Control	X	X	X

Table 1. The combinations for each treatment and a control group. O indicates that the corresponding modality will be included and X means the opposite.

Goals and Contributions

As the interfaces of new technology tools are becoming more multimodal (e.g., gesture, haptic) it is important to understand what a specific modality can bring into the design world. However, unlike visual or aural modality, temporal modality hasn't been explored as a form of representation in conjunction with other modalities to convey abstract information. The result of this study may inform the community of learning technology researchers and designers about whether and how a temporal representation can be used to expand the potentials of interactive multimedia. Additionally, it also points to the potential role of a non-typical modality in expanding our experience of the world. It shows that an interaction with a novel form of technology can alter the way people think about an abstract concept and consequently improves the comprehension of difficult knowledge. Finally, my research also demonstrates an example of how an educational challenge can be addressed by research that deals with HCI issue.

Citations

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