TAVR: Temporal-Aural-Visual Representation to Convey Imperceptible Spatial Information

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Abstract

This paper describes a study that investigated the use of time as a form of representation for imperceptible sizes by incorporating it in a multimodal representation that is designed to extend students' learning experience of the sizes of the objects beyond human sense (called submacroscopic objects). In this paper we introduce the research we conducted to explore how middle school students interpret and conceptualize the temporal representation.

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ACM Classification Keywords

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

General Terms

Design

Introduction

The role of external representations is particularly critical in teaching and learning the world beyond human senses because the phenomena at imperceptible scale cannot be experienced directly, and what learners perceive and conceptualize is mediated only by the external representations they use [4]. No one has ever directly seen what an atom looks like, but external representations enable us to visualize things that the physical tools do not allow us to see.

A number of learning technologies have been developed to support learners to understand scale beyond human senses by adopting various forms of external representations such as video (e.g., Powers of Ten [2]) or interactive visual representations (e.g., Scale Ladder [6]). Commonly used learning technologies convey imperceptible scales usually by providing alternative visual experiences of the sizes of the objects too small to see. For example, the visual representations of such objects are enlarged to a visible scale or they grow as a student interacts with them. In many cases such visual representations are presented with mathematical expressions (e.g., "the diameter of a Rhinovirus is about 40,000 times smaller than one millimeter") that require students to mentally visualize the sizes of the objects through proportional reasoning.

However, prior research [12] indicates that learners are likely to face cognitive challenges in interpreting and comprehending such visual representations of imperceptible scales. Frequent exposure to the macroscopic visual representations of submacroscopic objects (e.g., atoms, molecules, bacteria, virus, and cells) seems to cause students to overestimate the sizes of the objects. Some students even tend to think that the size of the visual representation of a submacroscopic object is the actual size of the object. As a result, students are inclined to believe that 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 as a grain of rice. This observation implies that visual representations may not always be useful for representing imperceptible scales that one cannot have direct visual experience.

Consistent with this observation, studies on human spatial cognition [5, 14] emphasize the centrality of direct personal experience, arguing that spatial cognition is most frequently based on what was perceived to exist and what had been already directly and visually experienced. The absence of direct visual experience of an object is the main reason that such misconceptions develop, and the visual representations that may misrepresent true are inappropriate to be the replacements for direct visual experiences. Therefore, a novel form of representation that does not require learners to depend on visual representation may help them better understand the imperceptible scales by altering the nature of the cognitive task that they have to deal with.

External representations co-determine the very nature of the human cognitive task, and the interaction with tools may enhance and transform human cognition because human activities are "mediated" by tools [13]. Recent theories such as "intellectual partnership [10]" between a learner and tool, "distributed intelligence [8]", "distributed cognition [3]" , and "representational effect [15]" also suggest that external representations shape or give rise to a learner's mental model of knowledge. External representations may allow a learner to understand a concept which could have been beyond his or her cognitive capability. Moreover, an external representation that directs learners to explore concepts in a different way may help them realize and revise their misconceptions [1].

In this regard, we propose an alternative representation that alters the way learners think about imperceptible scales. We suggest time (more specifically, duration of an event) as a main modality for representing imperceptible scale. It refers to duration of a sequential activity that happens on a space over a certain period of time (e.g., walking across a football field or placing strands of hair across the head of a pin at a certain velocity). The duration of the sequential action hence will represent the sizes or distances that the sequential action has happened on.

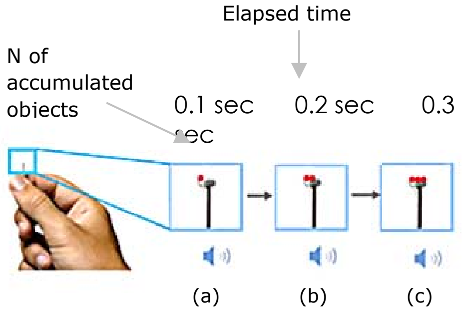


Figure 1. An illustration of the accumulation in TAVR.

(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.

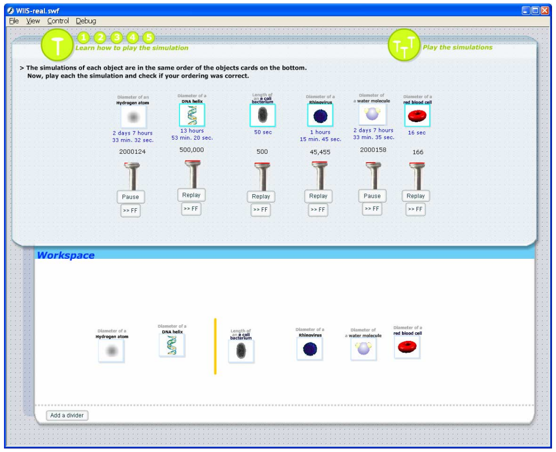
Temporal Representation for Representing Spatial Information

A Temporal-aural-visual representation (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 how a TAVR works.

The temporal aspect of the representation is the time it takes for an object to span across the pinhead. The goal is to use the 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 [7] 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. The smaller the object, the more objects are required to span the pinhead.

Application: Wow, It Is Small!

We designed Wow, It Is Small! (WIIS), a learning environment that students can interact with TAVRs for selected submacroscopic objects. WIIS is composed of a set of temporal-aural-visual representations (TAVRs) for different submacroscopic object and an interface to support learners’ sense making (see Figure 2 for a screen capture), following the scaffolding work in Quintana et al. [9]. Students can directly manipulate various TAVRs in drag-and-drop fashion to sort 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.



> The simulations of each object are in the same order of the objects cards on the bottom.
Now, play each the simulation and check if your ordering was correct.

Diameter of an Hydrogen atom	Diameter of a DNA helix	Length of an e coli bacterium	Diameter of a Rhinovirus	Diameter of a water molecule	Diameter of a red blood cell
2 days 7 hours 33 min. 32 sec.	13 hours 53 min. 20 sec.	50 sec	1 hours 15 min. 45 sec.	2 days 7 hours 33 min. 35 sec.	16 sec
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Figure 2. A screen capture of WIIS. The top of the screen is the simulation space where students use TAVRs and the bottom is a workspace to sort objects by size.

1 nanometer = 10^{-9} meters

1 micrometer = 10^{-6} meters

Task 1		
Set 1	**Set 2**	**Set 3**
16 seconds	1 second	1 second
50 seconds	16 seconds	16 seconds
1 hour	50 seconds	50 seconds
14 hours	2 minutes	2 minutes
4 days	30 minutes	30 minutes
12 days	1 hour	50 minutes
	14 hours	1 hour
	1 day	14 hours
	4 days	22 hours
	12 days	1 day
		4 days
		12 days
		36 days
		1 year
Task 2		
Set 1	**Set 2**	**Set 3**
16	1	1
50	16	16
3600	50	50
50400	120	120
345600	1800	1800
1036800	3600	3000
	50400	3600
	86400	50400
	345600	79200
	1036800	86400
		345600
		1036800
		3110400
		31536000

Table 1. The sets of time and numbers given to the participants for classification tasks.

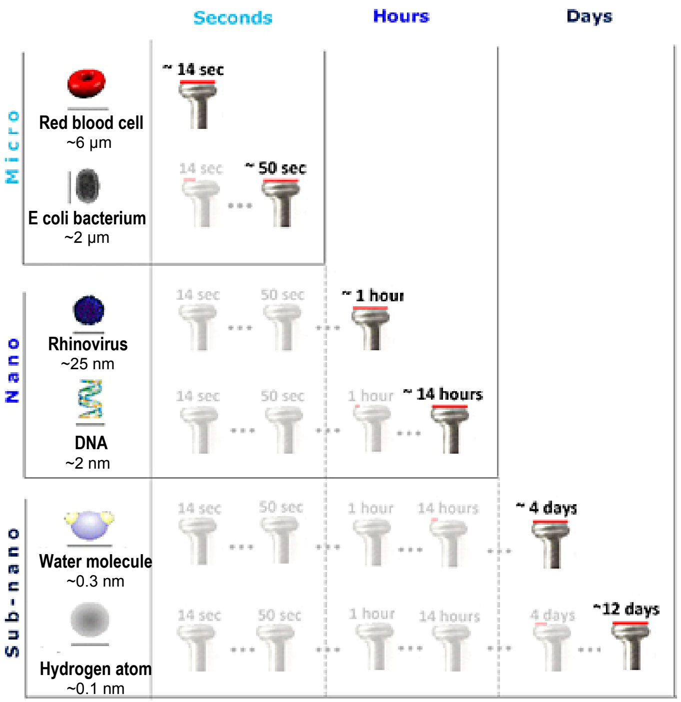


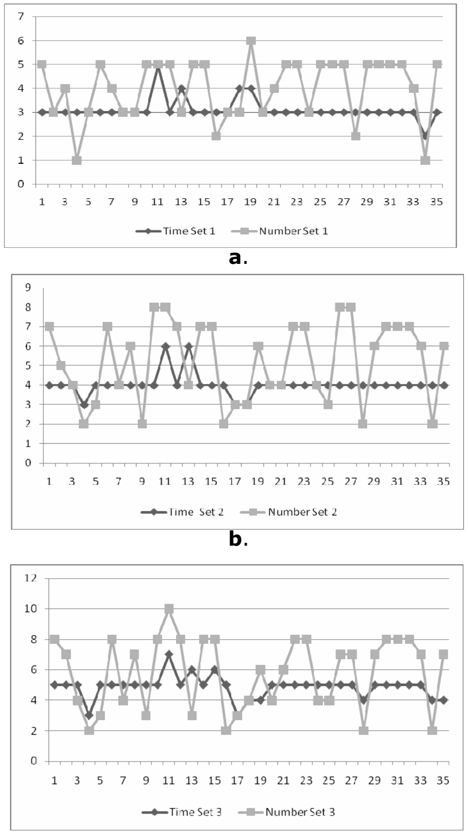
Figure 3. The sizes and the duration of accumulation for the submacroscopic objects used in this study

The Role of the Units of Time in TAVR

In our pilot study [11], we found that students could appropriately interpret TAVRs. The participating 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. We also found that their mental model of the sizes of the submacroscopic objects became more accurate after the learning activity with TAVRs. Although there did not exist strong unanimity in the way the students interpreted the relative differences between the durations, it was clear that time was a meaningful concept for learners that they could use to analogically construct deeper understanding of an abstract concept upon.

Based on these findings, we conducted interviews and surveys with thirty five 7th and 8th grade students (17 male and 18 female) to further investigate how the units of time shape the way learners interpret the imperceptible spatial information represented in TAVRs. Students were given two sets of tasks: (1) classifying three sets of durations of time into groups by similar length, and (2) classifying three sets of numbers into groups by similar magnitude (see Table 1 for these two sets they were asked to group). The sets of numbers used in Task 2 are the same durations of time converted in the units of seconds, but the students were not told about this fact. In this way we intended to expose the role of the units of time in TAVRs. The students were instructed to draw circles around each group they formed and to name the groups according to the reason behind their classification. They were told that there is no limit in the number of groups they could create. We hypothesized that most of the students would create groups of time by looking at the units of time, and the students would create a more number of groups for the sets of numbers because they may count the number of digits to classify the numbers (e.g., a group of numbers with four digits).

As expected, our result showed that many students (80%) grouped the sets in task 1 by the units of time (seconds, minutes, hours, days, and year), as in our prior study. However, the rest of the students (20%, 7



a.

b.

c.

Figure 4. Line graphs that illustrate the difference in the students' tendency of classification for the set of time and numbers. **a:** the comparison of the number of groups that each student made for set 1 in Task 1 and set 1 in Task 2. **b:** the comparison of the number of groups that each student made for set 2 in Task 1 and set 2 in Task 2. **c:** the comparison of the number of groups that each student made for set 3 in Task 1 and set 3 in Task 2.

students) used different strategies. For example, one student grouped the durations of time (in task 1) that are longer than 1 day into a "very long time" group, even together with 1 year. A couple of students converted 36 days into 1 month and 5 days and classified it as an independent "month" group. Unlike task 1, our prediction on how the students would classify did not match with what they actually did. Only a few students grouped the numbers by counting the number of digits, and the strategies were inconsistent between each student. Most of them grouped the numbers in task 2 following their own ways of interpreting the numbers, which had been constructed through their prior experiences in classrooms and daily lives. Therefore individual students gave different meanings to the numbers (especially the numbers larger than 1000), and their interpretations tended to be random and illogical.

Table 2 is the summary of the average and standard deviations of the number of groups that the students created for each set in the grouping task. The students made 3.1, 4, and 4.9 groups in average for sets 1, 2, 3 in Task 1, and more groups for each set in Task 2. Also, the greater standard deviations for the grouping Task 2 implies that the students tended to interpret the numbers in a less unified fashion than they did for the number that had units of time in Task 1. To visually illustrate the difference in the number of groups the students created, we generated line graphs for each set. As shown in Figure 4, the range of the variation of the number of groups that students created (black lines in the graphs) tends to be narrower for the time sets (Task 1), and the number of the groups that the students created is more unified than the number sets (Task 2) for each set. In contrast, the number of groups that the students created for the number sets (in grey lines) tend to be more spread and varying than the time sets. The students made more reasonable groupings when the information is presented with units of time. ☐

	Task 1			**Task 2**		
	Set 1	**Set 2**	**Set 3**	**Set 1**	**Set 2**	**Set 3**
Average	3.1	4.0	4.9	4.0	5.2	5.8
STD	0.5	0.6	0.7	1.3	2.1	2.4

Table 2. The average and standard deviations of the number of groups the students created for each set in the grouping task.

Conclusion

The units of time play a critical role in generating a more unified comprehension of the imperceptible scale information represented in TAVRs. The imperceptible spatial information can be less abstract and easier to understand for students when it is represented in TAVRs that adopts the units of time. As a next step, we are planning to investigate what components of TAVRs contribute to the successful TAVR interaction. TAVRs are 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, we will conduct an experimental study that explores the different effects with different combinations of each modality.

The nature of human cognition is multimodal. As the interfaces 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 modalities, temporal modality hasn't been explored as a form of representation in conjunction with other modalities to convey an abstract concept. 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 potential of interactive multimedia. Additionally, this research also 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 new information. Our research also demonstrates an example of how an educational challenge can be addressed by research deals with HCI issue.

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