Research Reports

Accuracy of Estimations of Measurements by Students with Visual Impairments

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There is a dearth of information about how students with visual impairments learn science-process skills. The study presented here investigated students' concepts and skills in one science area: the estimation of measurements. The estimation of measurements is one of the fundamental concepts that connects all science disciplines that provide the necessary skills to understand the natural world (National Research Council, 1996; Roth & Roychoudhury, 1993) and is an instructional goal at every grade level of the *Mathematics Standards* (National Council of Teachers of Mathematics, 2000). Estimating is as important in the science laboratory as it is in real-world environments. In the laboratory, students are asked to make measurements using tools, such as rulers, balances, and beakers, all of which typically rely on visual perception. Although adaptive technologies are available to a small sample of students, these tools are not universally available for those who need them in mainstream classes (Jones, Taylor, & Broadwell, 2009a). The purpose of this study was to document the reported experiences of students with visual impairments with estimating measurements, as well as the students' conceptualizations of linear distances and accurate estimations.

Methods

Participants

The participants were 15 middle school students who were legally blind (9 from birth) (Hollins, 1989). One student had no vision, and the others had low vision (all were braille readers). The participants attended public schools and had been mainstreamed into regular education programs. Of the 15, 3 were girls and 12 were boys (7 were European Americans, 4 were African Americans, and 3 were Hispanics) with an average age of 12.4 (SD = 1.6). The study was approved by the North Carolina State University Institutional Review Board, and consent to participate was given by the students and their parents.

Procedures

While the participants attended a program on emerging technologies that are designed for students with visual impairments at a large southeastern university, they were invited to volunteer to participate in a research study that was separate from the activities of the technology program. The students were asked a brief series of questions to determine their previous experiences with measurement and estimation:

- Have you ever been taught how to measure the length of an object? Please describe your experiences.
- Have you ever used a meter stick to measure the length of an object? Please describe your experiences.
- Have you ever used measurement tools outside the classroom? Please describe your experiences.
- Have you ever been taught how to estimate the length of an object without using a measuring tool? Please describe your experiences.

During the interviews, the students' oral responses were recorded. The participants were asked to perform a series of measurement tasks. Test items were pilot-tested with youths with visual impairments to determine their appropriateness for this study. Each of the estimation sizes is typical of those that students would make in middle and high school classrooms.

The first task required the students to demonstrate with their hands on a piece of paper a variety of lengths (millimeter, centimeter, meter, and foot). The students' estimates were recorded by the researchers on the paper. The second set of tasks involved the students estimating the length of selected objects using various units. The students first estimated the length of vertical and horizontal dowel rods (91 centimeters, or about 36 inches, long) in both centimeters and inches. The students were given the opportunity to feel the rods that were fixed to the wall to allow them to examine the spatial orientation. Next, they were asked to estimate the length in centimeters of two lines of three-dimensional "puffy" paint. One line was painted on typical white paper, while the other was painted on paper that contained raised dots (providing tactile distracters). This task examined the impact of haptic distracters on the accuracy of estimation.

For the fourth task, the students estimated the height and width in millimeters of a small wooden (three-dimensional) cylinder. This task examined the role of dimensionality in accurate estimations. For the final task, the students walked a hallway for a set distance and estimated its length in meters.

Results

Experience with estimation and measurement

Experiences learning to measure. Thirteen students mentioned that they had experience with measurement and estimation through school. The majority of the examples they cited had to do with exercises in geometry, such as measuring diameters of circles, sides of cubes, lengths of lines, and perimeters of shapes. Five students mentioned that they had measured things in their classes without giving specific examples.

Experiences using meter sticks. Six students reported having used a meter stick to measure linear distances, and several confirmed that they did so in science or mathematics courses. Five students insisted they had not used a meter stick to measure, and four gave no response.

Using measurement tools outside school. The participants cited a number of examples in which they had learned about measurement and estimation through experiences at home. One student explained how her mother had taught her to estimate the amount of tea in her glass by using her finger and to estimate the size of the house by counting "paces" around the edge. Seven students reported that their experiences with measurement and estimation took place in the kitchen.

Experiences measuring without tools. Twelve students had learned about estimation in school. However, the participants had a hard time defining estimation. One student stated that estimation "is just guessing," while another said, "it's kind of a common skill, . . . but it doesn't have a specific meaning [definition]; it's like rounding." The most common example of estimation given by the students was estimating linear distances in hallways for the purpose of navigation.

Conceptions of linear distances

The students were asked to provide visual representations of their estimates for specific linear distances (see Table 1). There was a wide range of accuracy in the students' responses. For example, one student estimated a centimeter to be equivalent to 59 centimeters. Means and standard deviations are reported in the table to give a sense of the standard within the highly variable estimations. Percentage error calculations are shown to normalize between the different measurement units. The students had a weaker conceptualization of small distances (millimeters and centimeters) than they did of large distances (feet and meters).

Table 1
Participants' conceptions of linear distances.

Distances	Minimum	Maximum	Mean	*SD*	Percentage error
Millimeters	0.50	30.50	7.86	11.45	61.20
Centimeters	0.50	59.00	6.50	14.88	55.30
Feet	0.71	2.33	1.35	0.95	3.50
Meters	0.00	1.75	0.47	0.41	5.30

Accuracy of linear estimation

The accuracy of estimation for the different estimation tasks is shown in Table 2. Because of the small sample and the variability of the results, care should be taken before generalizing beyond the context of this study.

Comparisons were made of the accuracy of estimation of object orientation (vertical versus horizontal) and units (centimeters and inches) for the wooden dowel rods. In general, vertical estimates tended to be higher than horizontal estimates (with high variability). This finding indicates that the students did not recognize that the dowel rods were in fact the same size and hence did not adjust their estimations accordingly. Second, in both orientations, the students were more accurate with English units than with metric units.

When estimating the length of the puff-paint lines, one of which had raised bump distracters, the students were less variable in their estimations. The students' estimations of a line that contained a tactile distracter were less accurate than they were for a line without the distracter.

When the students were asked to estimate the height and width of a wooden cylinder, they were more accurate at estimating the width as opposed to the height. More than for any of the other tasks, the students were most accurate at estimating the length of a hall when pacing it.

Discussion

The results showed that the students with visual impairments lacked skills in making linear estimations and had particular difficulty estimating metric lengths. Given the need to be fluent in making estimations in science, this is a skill that should be taught more explicitly.

Table 2
Participants' accuracy of estimation of linear distances.

Tasks	Minimum	Maximum	Mean	*SD*	Percentage error
Dowel rod task					
Vertical (centimeters)	1.50	300.00	73.07	89.81	19.70
Vertical (inches)	10.00	75.00	30.57	17.90	14.66
Horizontal (centimeters)	1.00	240.00	47.13	58.89	48.21
Horizontal (inches)	11.00	50.00	27.43	12.43	23.42
Raised line					
Solid background (centimeters)	1.00	11.00	5.79	3.40	39.05
Bumpy background (centimeters)	1.00	10.00	4.46	3.25	53.05
Cylinder					
Height (millimeters)	1.00	50.00	6.46	13.02	54.60
Width (millimeters)	2.00	50.00	12.86	12.53	35.70
Hall length (meters)	7.00	15.00	19.21	9.96	3.95

Experience with estimation

Most of the students reported experiences with estimation and measurement both in their school and outside the classroom. Although the estimation of measurements is a key component of science and mathematics education at almost all grade levels, the majority of examples the students provided were in mathematics courses.

What is positive in these results is that the students cited examples of using estimation skills outside school. During the brief interviews, we got the sense that the students may not have connected informal estimation experiences with the skills required in formal scientific inquiry. Future interventions to improve estimation skills may focus on out-of-school experiences.

Relating the ability to estimate to size

Across the tasks, the students were better able to estimate when measurements were close to the human scale. Previous studies have shown that measurements that are less than a millimeter are difficult for students with and without visual impairments (Jones et al., 2007; Tretter, Jones, & Minogue, 2006; Tretter, Jones, Andre, Negishi, & Minogue, 2006). For the students with visual impairments in this study, the difficulty extended to measurements of centimeters. One explanation for the difference is that students with visual impairments have fewer opportunities to measure centimeters and lack visual information that can be used when making a conceptual representation. It is possible that some students may have read about metric units and listened as their teachers taught about metric units, but had not directly experienced making metric measurements.

Studies have shown that people often use their bodies as a measurement tool in making estimations, such as measuring centimeters with the width of a finger (Jones & Taylor, 2009). None of the students in this study mentioned having experiences using his or her body as a ruler. However, in studies with sighted children, the accuracy of estimation has been shown to be tied to the relationship of the units to the human body (Jones, Taylor, & Broadwell, 2009b).

Previous research has shown that people tend to be less accurate when estimating vertical lengths than when estimating horizontal lengths because of the horizontal-vertical illusion, which suggests an overestimation of vertical measurements. However, the illusion does not apply when the stimulus is small and haptic methods are used (Heller, Calcaterra, Burson, & Green, 1997). Our data did not support the horizontal-vertical illusion hypothesis because the majority of the students with visual impairments could not estimate the length of a dowel rod within a 40% error rate, whether oriented vertically or horizontally. This inability to estimate could be due to the haptic method of finger tracing that the students used.

While most of the tasks were two dimensional, three-dimensional wooden cylinders were included to provide information about whether the students would be more accurate in estimating units of a three-dimensional object. The results showed that complete tactile access did not appear to make the students any more accurate than with the other tasks.

Because students with visual impairments are compelled to learn to estimate distances accurately while navigating during walking, it seems likely that they would be particularly accurate in making estimations of lengths. This was true for half the participants who were able to estimate the length of a hallway with an error rate of 40% or less. The difficulty that the students had with small metric estimations is problematic, given the significant advancements in science that are taking place at the small end of the scale (such as nanotechnology). Students with visual impairments may be adept in navigating the world they can experience directly, but it is still unclear how they meaningfully conceptualize a scale that goes beyond that world (Jones, Taylor, & Broadwell, 2009a).

Future research

More research is required to determine what types of adaptive measurement tools are most effective with students with visual impairments. Research is also needed to document how students who use tactile learning media form concepts of metric units and apply them in concrete and abstract contexts.

We cannot afford for any child not to be knowledgeable about science, regardless of whether they become scientists or not. The results of this study suggest that teachers may need to focus instruction on strategies that students with visual impairments can use to estimate, such as using body parts. Teachers may need to verbalize strategies that students can use to estimate small sizes and to provide multiple strategies for making metric measurements. Significantly more research is needed to understand how students with visual impairments learn science, how teachers can best provide adaptations and instruction, and how laboratories can be structured to meet the needs of all students.

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