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Gender differences in understanding of thermal expansion

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Abstract: Investigation of gender differences in science allows us to tailor our instruction to the needs, interests and abilities of all our students. In this study we aimed to investigate gender differences in conceptual understanding of thermal expansion. To that end ten conceptual questions were administered to 195 first year students at the Faculty of Chemical Engineering and Technology, University of Zagreb. Male students significantly outperformed female students. Particularly large differences in favor of males were observed on questions that required reasoning about thermal expansion in one dimension.

INTRODUCTION

Differentiation of instruction is defined as factoring students' individual learning styles and levels of readiness before designing a lesson plan (Tomlinson, 2000). In order to be in the position to effectively differentiate instruction, it is important to be well acquainted with knowledge about students' individual differences and skills, as well as with gender differences (Tomlinson, 2000; Halpern et al., 2007). As a matter of fact, by knowing gender differences in learning science, we can more effectively plan conceptualization and conceptual change for all our students. Gender differences in science are typically analyzed from two perspectives: biological and environmental. According to the biological perspective it is often desirable to look for gender differences very early in life to find clues to relative contribution of biological factors (Kotovsky and Baillargeon, 1998; Phillips, Wellman, &Spelke, 2002; Xu). A common finding from many studies that were focused on early age is that cognitive skills related to knowledge of objects in the environment and quantitative thinking are equally well developed in boys and girls (Spelke, 2005).

According to the environmental perspective, abilities are developed under the supportive influence of environment and learning experiences (Halpern et al., 2007). Many studies showed that differences in choosing science careers are influenced by the social structures where individuals are situated, environment resources and the social interactions in which subjects are involved (Eccles, 1994; Entwistle, Alexander, Olsson, 1994; Xie and Shuman, 2003).

Halpern (2000, 2004) emphasized that it is very hard to separate environmental influences from biological ones because they are in constant interaction. Consequently, she advocated a biopsychosocial approach to studying gender differences. According to that approach, learning is influenced by biological and environmental factors because environmental events such as social victories or defeats stimulate endocrine glands to secret chemicals that are affecting a variety of behaviors and brain development (Schultheiss et al., 2005).

Much of earlier research shows that boys outperform girls on visuospatial tasks (Voyer, Voyer, Bryden, 1995; Loring-Meier and Halpern, 1999), whereas girls outperform boys on verbal tasks and writing (Bae et al., 2000; Ogle et al., 2003). There are many topics in science that require visual reasoning and mental simulation (Nersessian, 2008). Although girls and boys on average are equally successful in science, earlier research shows that on certain tasks boys largely outperform girls. These tasks are mainly related to visuospatial reasoning and one such task is the water-level task (Myer and Hensley, 1984; Hecht and Proffitt, 1995). Furthermore, Burkitt, Widman and Saucier (2007) showed that males outperformed females in the tasks that were arranged in the 3-D graphical virtual reality environment.

A science topic that requires rich visualization and mental simulation is thermal expansion. As a matter of fact, in order to understand thermal expansion one has to visualize and mentally simulate the model of particulate nature of matter. Thereby thermal expansion is explained

by the fact that heating results in faster motion of particles which, together with asymmetric shape of the potential energy well, leads to an increase in average interparticle distance. However, earlier research shows that students have many misconceptions related to this topic (Erceg, Aviani, Mešić, Glunčić and Žauhar, 2016). In the study by Yeo and Zadnik (2001) it has been shown that students often thought that the temperature of an object depends on its size. In addition it has been found that students often wrongly assume that phase changes are associated with a change of the size of particles (Yalcınkaya and Boz, 2015). Another well-known misconception is that in objects with holes the diameter of the hole decreases as a result of heating (McHugh and McCauley 2016; Watkins and Mazur 2013).
Generally, it seems that many of these difficulties stem from the fact that students tend to transfer their experiences from the macroscopic world to the invisible, microscopic world (Duit, 2015).

Aim of the present study

In this study we aimed to investigate gender differences in understanding of thermal expansion. This is potentially significant because it provides us with feedback that can improve the effectiveness of differentiating our instruction about that introductory science topic.

Methodology

Research design

To answer our research question we conducted a survey research after lectures and recitation sessions about thermal expansion.

Participants

Our sample consisted of 195 first year students at the Faculty of Chemical Engineering and Technology, University of Zagreb (Croatia). All the students from our sample (mostly 19 year-olds) were enrolled in the first year introductory physics course. In our sample 73% of students were females.

Curriculum and teaching treatment

Before they took our survey, all the students from our sample received traditional lectures about thermal expansion. The introductory physics course can be characterized as a typical introductory physics course for scientists and engineers in Croatia. Thermal expansion phenomena was firstly explained in lectures where the accent was on facts and procedures. Thereafter students additionally learned about this topic in recitation sessions.

Assessment instruments

In this study we aimed to investigate gender differences in conceptual understanding of thermal expansion. To that end, a conceptual survey has been created. Short description of the survey is provided in Table 1. From Table 1, it follows that our survey consisted of multiple choice items and open ended items. In multiple-choice items, we used common student misconceptions as distractors.

Table 1: Short description of the conceptual survey

Item 1	Item 2	Item 3	Item 4a	Item 4b
Predicting the length increment of rods with different initial lengths	How difference in thermal expansion coefficients of liquid and container affect the liquid level?	How heating affects the distance among two straight rods positioned along the x-axis?	How temperature change affects the vertical heights of several rectangular plates?	How temperature change affects the surface area of several rectangular plates?
Multiple-choice	Open-ended	Multiple-choice	Open-ended	Open-ended
Item 5	Item 6	Item 7	Item 8	Item 9
How heating affects the appearance of a circular plate with a hole	How heating affects appearance of two concentric circular plates (same material)	The effect of heating on the expansion of a ring and a straight rod that is placed inside the ring, along its diameter.	How heating affects the appearance of two concentric circular plates made of different material.	How heating affects the three-dimensional spatial arrangement and size of particles in a metal.
Multiple-choice	Multiple-choice	Multiple-choice	Multiple-choice	Multiple-choice

RESULTS

We conducted an analysis of variance (ANOVA) in order to check between-gender differences on the given ten survey items. Results of ANOVA showed that there was a statistically significant difference between male and female students on the selected test items, $F(1, 193)=8.192$, $p<0.01$, partial $\eta^2=0.041$.

In what follows, we will focus our attention on presenting the results for four multiple-choice items with most prominent gender differences.

Table 2 provides a summarized overview of students' achievement on four multiple choice items.

Table 2: A summarized overview of average proportion of correct answers for male and female students is provided. Standard deviations are given in parentheses.

	Item 1	Item 5	Item 6	Item 9
Male students	0.65 (0.48)	0.56 (0.50)	0.56 (0.50)	0.79 (0.41)
Female students	0.45 (0.5)	0.40 (0.49)	0.45 (0.49)	0.63 (0.48)

From Table 2 we can conclude that male students outperformed their female colleagues on all four test items. Most prominent difference (21%) was found for Item 6.

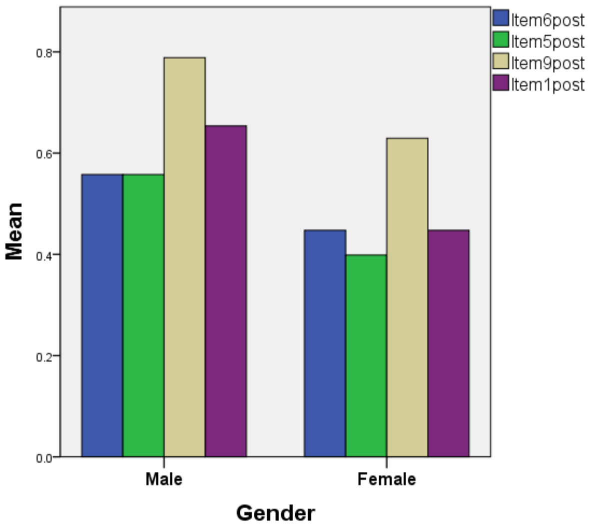

Figure 1: Proportion of correct answers on individual test items

From Figure 1 it is easy to notice that the between-gender score differences are pronounced for all four items.

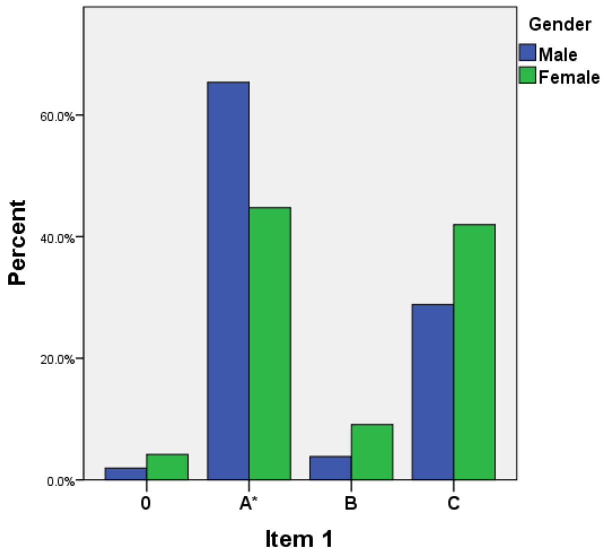

Figure 2: How frequently male and female students chose the given answering options for Item 1. The asterisk denotes the correct answer and a zero denotes missing answers.

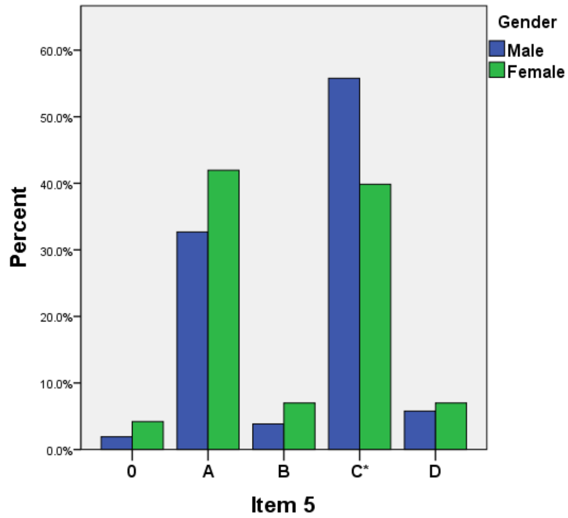

Figure 3: How frequently male and female students chose the given answering options for Item 5. The asterisk denotes the correct answer and a zero denotes missing answers.

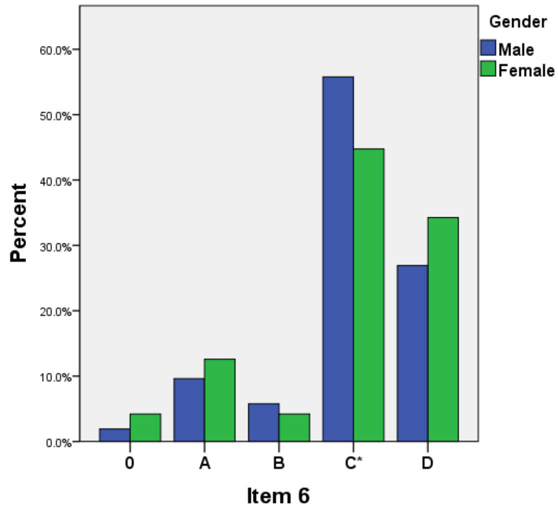

Figure 4: How frequently male and female students chose the given answering options for Item 6. The asterisk denotes the correct answer and a zero denotes missing answers.

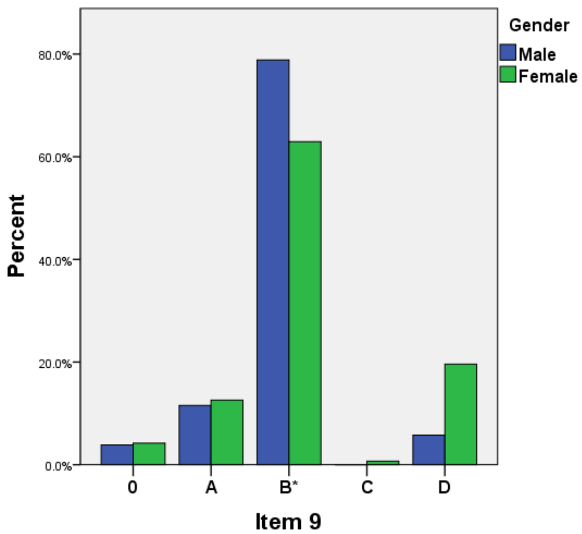

Figure 5: How frequently male and female students chose the given answering options for Item 9. The asterisk denotes the correct answer and a zero denotes missing answers.

Figures 2, 3, 4 and 5 provide information about the frequency of choosing individual answering options in Items 1, 5, 6 and 9 for male and female students.

DISCUSSION

From Table 2 it follows that male students outperformed female students on all four items. However, it should be also noted that generally the proportions of correct answers were relatively low on three out of four items. Such low scores are not surprising because in earlier research many student misconceptions have been reported about this scientific topic (Yeo and Zadnik, 2001; Yalcınkaya and Boz, 2015). An alternative explanation for the low scores could be related to the fact that in the traditional lectures the accent was put on factual and procedural knowledge.

Most prominent between-gender differences on individual items

Next, we are going to discuss the between gender differences on selected items.

In Item 1 students were asked to compare the thermal expansion of rods with different initial lengths. Visualizing the process of thermal expansion could have facilitated solving of this item. As a matter of fact, one can model a rod as consisting of many particles connected by springs. Heating results in elongation of these springs. A larger initial length of the rod is associated with a larger number of atoms/springs which results in a larger total increase of length. On this item male students scored 20% higher than female students.

In Item 5 students were showed a circular plate with a hole and they were supposed to predict what will happen with the area of the plate as a result of heating. In other words, students had to reason about two dimensional (or area) thermal expansion, in order to correctly solve this item. Again, male students outperformed their female peers by 16%.

In Item 6 students were showed two circular plates (made of same material) with a hole and they were required to predict what will happen with area of these plates as result of heating. In order to correctly solve this item students had to reason about area thermal expansion, as well as to take into account of the different initial surface sizes. In this item male students scored 11% higher than their female colleagues.

In Item 9 students needed to predict how heating influences particles inside a metal (three dimensional expansion). In order to correctly solve this item students needed to understand that increase of metal's volume that was subjected to heating is not result of an increase in volume of the atoms but it is a result of an increase of average interparticle distance. In this item male students scored 16% higher than female students.

Finally, we can conclude that our data consistently supports earlier findings related to male's higher performance on visuospatial tasks (Voyer, Voyer, Bryden, 1995; Loring-Meier and Halpern, 1999; Myer and Hensley, 1984; Hecht and Proffitt, 1995).

Students' misconceptions about thermal expansion

Next, we will discuss the identified misconceptions for our four test items.

In Item 1 students were required to reason about one dimensional thermal expansion. From Figure 2 we can see that most common wrong answer for Item 1 was answer C (male students - 29%, female students – 42%). Incorrect option C reflects the erroneous belief that length increment depends *only* on the amount of temperature increase. We can see that this misconception was much more pronounced in female students than in male students. It seem that in the male subsample there were more students who tried to approach this problem by using visuospatial reasoning which resulted in a better performance of male students.

In Item 5 and Item 6 students were expected to reason about two dimensional thermal expansion ie. to describe the effect of heating on the area of the presented plates.

From Figure 3 we can see that the most frequent wrong answer for Item 5 was answer A (male students – 33%, female students - 42%). This wrong answer reflects a well-known misconception according to which the plate's hole is shrinking as a result of heating (Watkins and Mazur, 2003; McHugh and McCauley, 2016). This misconception could stem from the fact that students tend to approach this problem by visualizing what happens in one dimension (x or y-axis) only. It seems that in the subsample of male students there is a larger percentage of students who approach this problem by simultaneously visualizing changes along the x- as well as along the y-axis.

From Figure 4 it follows that the most common wrong answer for Item 6 was answer D (male students - 27%, female students - 34%). In other words, similarly as in Item 5, many students wrongly believed that holes in the circular plates shrink as a result of heating. (Watkins and Mazur, 2013; McHugh and McCauley, 2016).

In Item 9 students had to apply the three dimensional model of particulate nature of matter in order to predict effects of heating a metal. From Figure 5 we can see that the most common answer for Item 9 was D (20%) for female students and A (6%) for male students. Both answers reflect the common misconception that when thermal expansion happens atoms are getting bigger (Yeo and Zadnik, 2001; Yalcınkaya and Boz, 2015).

It should be generally noted that students were more successful on the item that required reasoning about one dimensional expansion than on items that required reasoning about two dimensional expansion. Reasoning about two dimensional expansion was more demanding, for both, the male and female students. In other words, items that required two dimensional visualization probably induced a higher intrinsic load which negatively influenced the students' performance (Sweller, 1994).

Finally, we need to note that the main limitation of our study is related to the relatively small sample of conceptual items. However, it should be also noted that the measured construct (conceptual understanding of thermal expansion) was also relatively narrow which could justify the selection of a small number of items.

CONCLUSION

In this study we aimed to investigate gender differences in reasoning about thermal expansion.

The conclusions from our study are as follows:

- Generally, male students significantly outperform female students in solving qualitative problems about thermal expansion. This is particularly true for problems that require visual reasoning.
-Between-gender differences were lower on tasks that required reasoning about two dimensional thermal expansion which could be related to a higher intrinsic load of these tasks (Sweller, 1994).
- Our results support earlier findings according to which male students outperform females on visuospatial tasks (Voyer, Voyer, Bryden, 1995; Loring-Meier and Halpern, 1999).

In future studies about students' understanding of thermal expansion it could be useful to implement a mixed research design (Creswell and Clark, 2011) which would allow us to more deeply explore the patterns of students' reasoning.

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Summary/Sažetak

Istraživanje spolnih razlika u znanosti omogućuje nam da prilagodimo podučavanje prema potrebama, interesima I sposobnostima svih naših studenata. U ovom istraživanju smo nastojali istražiti spolne razlike u konceptualnom razumijevanju toplinske ekspanzije. U tu su svrhu 195 studenata prve godinena Fakultetu Kemijskog Inženjerstva I Tehnologije Sveučilišta u Zagrebu je rješavalo deset konceptualnih pitanja. Studenti su znatno nadmašili studentice. Posebno velike razlike u korist studenata su zabilježene na pitanjima koja su zahtijevala rasuđivanje o toplinskoj ekspanziji u jednoj dimenziji.