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The effects of a context-rich approach in teaching thermodynamics

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Abstract: Earlier research shows that at all educational levels students have many misconceptions about thermal phenomena. Often these misconceptions are related to difficulties with differentiating the meaning that concepts have in everyday language and in the language of science. In this study we aimed to investigate the effects of enriching traditional instruction about thermodynamics with qualitative and quantitative examples from everyday life. To that end we conducted a pre-post quasi-experiment with 114 high-school students (mostly 15-year-olds) divided into four subgroups. Two subgroups (n=60) received the traditional instruction, whereas in the remaining two subgroups (n=54) a context-rich approach to learning thermodynamics has been implemented. Analysis of covariance showed that there are no statistically significant between-group differences when it comes to conceptual understanding of thermodynamics. However, the context-rich approach proved to be significantly more effective when it comes to increasing students' interest in science. The level of aroused interest was higher in girls than in boys.

INTRODUCTION

Our students begin developing mental models about natural phenomena long before they enter formal education (Driver, Guesne, Tiberghien, 1985). Thereby their ideas about real-world objects and processes form spontaneously, mainly through physical experience with the environment (Bransford, Brown, Cocking, 2000). Taking into account that these ideas help the children to cope with everyday life, with time they become deeply rooted in children's cognitive systems (Redish, 2003). Consequently, children enter formal education with strong preconceptions about their natural environment. According to basic principles of constructivism the effectiveness of learning new concepts in science classrooms mostly depends on the level of students' mental efforts, as well as on the characteristics of students' preconceptions (Bransford, Brown, Cocking, 2000). Learning is significantly impeded if students' preconceptions are not scientifically accurate and such preconceptions are often called misconceptions or alternative conceptions (Driver, Guesne, Tiberghien, 1985).

One of the branches of science for which students' misconceptions are particularly pronounced is thermodynamics. As a matter of fact, it has been shown that at all educational levels students have difficulties with differentiating heat from temperature, as well as with differentiating these concepts from internal energy (Sozbilir, 2003). Furthermore, many students believe that clothes keep us warm by generating heat (Lewis, 1996) and that heating an object is always associated with an increase of that object's temperature (Driver, Guesne, Tiberghien, 1985). Finally, a common misconception is also reflected in the believe that heating is the only way for increasing the temperature of an object, although from the First law of thermodynamics it is clear that doing work on/by the system can also cause a change in temperature (Loverude, Kautz, Heron, 2002).

Taking into account that students' misconceptions about thermal phenomena are mostly rooted in their everyday language and experiences (Fox and Wilkinson, 1997), overcoming these misconceptions is very hard to achieve. In other words, the process of conceptual change requires investment of significant mental efforts from the student. Students' readiness to invest significant efforts into learning is closely related to students' motivation and interest for learning of science. Schunk, Pintrich and Meece (2008) define motivation as an intellectual process responsible for starting, directing and maintaining learning activities. From the expectancy-value theory it follows that students' motivation can be increased by creating learning situations that students consider to be important for their lives, as well as by developing in students a feeling of self-efficacy (Eggen and Kauchak, 2010). Similarly, two defining dimensions of the interest construct are (Wiesner, Schecker, Hopf, 2013): a) perception of importance of the given object b) associating the given object with positive emotions. Most of the students who are enrolled in physics classes can be categorized into one of the following categories of types of interest (Mueller, 2006): a) physics and technology b) human body and nature c) physics and society.

It is important to note that developing students' interest for science should not be perceived as a mere tool for improving cognitive achievements in science – developing interest in science is a worthy goal on its own because it increases the probability of life-long learning and choosing a career in science (Wiesner, Schecker, Hopf, 2013).

Aim of the present study

Although the idea of implementing authentic learning in science classes appears to be theoretically appealing, results of a meta-analysis show that in more than 50% of studies context-rich approaches proved to be equally effective as traditional instruction (Bennet, Lubben, Hogarth, 2006). There are also studies in which context-rich instruction was found to be significantly more effective than traditional instruction (see Yager and Weld, 1999), as well as studies in which it proved to be significantly less effective than traditional instruction (see Lubben, Campbell, Diamini, 1997).

As a matter of fact, although context-rich approaches often positively affect the students' motivation for learning science, sometimes real-world examples require various types of knowledge that are not systematically connected within the knowledge system of the corresponding scientific discipline (Mueller, 2006). Consequently, such learning environments are often less structured which can impede development of conceptual understanding (Kirschner, Sweller, Clark, 2006).In this study we aimed to investigate how a context-rich approach to teaching thermodynamics affects the conceptual understanding and interest for science in high-school students. Thereby we attempted to overcome the well-known difficulties of context-rich approaches by providing the real-life examples only in review lessons.

This study potentially contributes to a better understanding of factors that moderate the effectiveness of context-rich approaches to teaching science.

Methodology

Research design

In order to answer our research question we conducted a pre-post quasi-experiment (Cook, Campbell, Shadish 2002) with one group receiving traditional instruction and one group receiving the experimental treatment.

The treatment lasted for four teaching hours (four review lessons). One week before and after the treatment students were administered the pretest and posttest, respectively.

Participants

Our study included 114 students who were enrolled in the first year of a high-school in Zenica (Bosnia and Herzegovina). At the time of the study most of the participants were 15 years old. The sample included 44 male and 70 female participants and the gender distribution across the comparison groups was approximately the same.

Two classes (n=60) were assigned to the traditional treatment and the remaining two classes (n=54) to the experimental treatment.

Curriculum and Teaching treatment

Our quasi-experiment has been conducted as part of the regular curriculum. The development lessons in both, the control and experimental group, followed a traditional approach to teaching thermodynamics. These lessons typically began by review of earlier covered, relevant concepts. Thereafter the teacher attempted to introduce new concepts, establishing thereby connections to students' foreknowledge. Eventually, the teacher modeled solving of quantitative problems, i.e. she showed the students how to apply the newly introduced concepts. Development lessons have been followed by review lessons. In these lessons the approach to learning thermodynamics was different for the two groups. The control group continued to follow the traditional approach characterized by reviewing factual knowledge and solving of quantitative problems. On the other hand, in the experimental group the students were given the opportunity for context-rich learning. They were required to transfer the knowledge they learned in development lessons to carefully chosen real-world problems. These problems were mostly situated into the contexts of everyday life and simple hands-on experiments. Some contexts were selected from *Physics of Everyday Life* by Bloomfield (2006). If hands-on experiments were included, we attempted to also situate the quantitative examples within the context of these experiments. More detailed insight into differences between the two treatments can be gained through analysis of Table 1. Besides the topic from Table 1, our treatments also included the following topics: "Structure of matter. Molecular-kinetic theory of gases. Ideal gas law", "Laws of thermodynamics. Entropy. Work done by ideal gas. Heat engines".

Table 1: Review lessons about "Heat transfer. Specific heat capacity. Phase change"

Traditional treatment	**Context-rich approach**
Firstly factual knowledge about heat transfer, specific heat capacity and phase change was reviewed. Thereafter four quantitative problems were solved. One student modeled problem solving at the blackboard and other students engaged in discussion about problem solving while simultaneously solving the problem in their notebooks.	Students' were presented with a hands-on experiment in which one hand is put into hot water and the other hand in cold water. Then both hands were put into lukewarm water. The discussion of this experiment was supposed to help the students to think about heat transfer, as well as to differentiate heat from temperature. Different mechanisms of heat transfer were thoroughly discussed within the context of heating homes with woodstoves (Bloomfield, 2006), as well as within the context of a thermos bottle. Next, specific heat capacity was discussed within the context of passive solar heating (Etkina, Gentile, Van Heuvelen, 2013). For purposes of developing understanding of phase changes the contexts of an espresso machine and pressure cooker were used.

Assessment instruments

In this study students' understanding of thermodynamics is related to their ability to interpret, explain or predict thermal phenomena and representations (Anderson and Krathwohl, 2001).

Before the beginning of the treatment, students' understanding of thermal phenomena had been measured by the *Thermal Concept Evaluation* (Yeo and Zadnik, 2001) which consists of 26 conceptual questions. It is important to note that TCE is a widely known and extensively validated instrument.

For purposes of the posttest, we created an instrument consisting of 7 open-ended and 20 multiple-choice questions. The questions were mainly chosen from widely known introductory physics textbooks and they covered the concepts that were introduced in the treatments. A brief description of the posttest items is provided in the Appendix.

At pretest, as well as on the posttest, each correct answer has been awarded by one point.

For purposes of measuring the treatment effects on students' interest for thermodynamics, the students were expected to express their attitude towards the following statement: "*The way we learned about thermodynamics aroused in me interest for learning about thermal phenomena*".

Another statement for which students from the experimental group were expected to express their attitude was as follows: "*I would like if we could learn other physics topics in a similar way we learned thermodynamics*". Students were supposed to answer both these items by using a five-point Likert-scale.

Finally, students from both groups were also asked to report their general impression about the teaching treatment.

RESULTS

Between-group differences in conceptual understanding of thermodynamics

Between-group differences in conceptual understanding at pretest and posttest are presented in Table 2.

Table 2: Students' scores on the conceptual tests

Treatment		**Mean**	**Standard deviation**
Traditional approach (TA)	Pretest	6.75	2.14
	Posttest	10.03	3.05
Context-rich approach (CA)	Pretest	7.72	3.61
	Posttest	9.65	3.76

In order to check whether the between-group differences from Table 2 are statistically significant we have conducted an analysis of covariance (ANCOVA). Results of ANCOVA showed that the between-group differences in conceptual understanding were not statistically significant, $F(1,111) = 0.06$, $p = 0.81$.

Finally, it is also interesting to investigate whether the treatment effects are moderated by gender (see Table 3).

Table 3: Treatment effects moderated by gender

Gender	Group		Mean	Standard deviation
Male	TA	Pretest	7.19	2.56
		Posttest	10.76	2.98
	CA	Pretest	7.61	3.54
		Posttest	8.96	4.08
Female	TA	Pretest	6.51	1.86
		Posttest	9.64	3.05
	CA	Pretest	7.81	3.71
		Posttest	10.16	3.48

Figure 1 allows us to compare the treatments' effects on students' interest for thermodynamics.

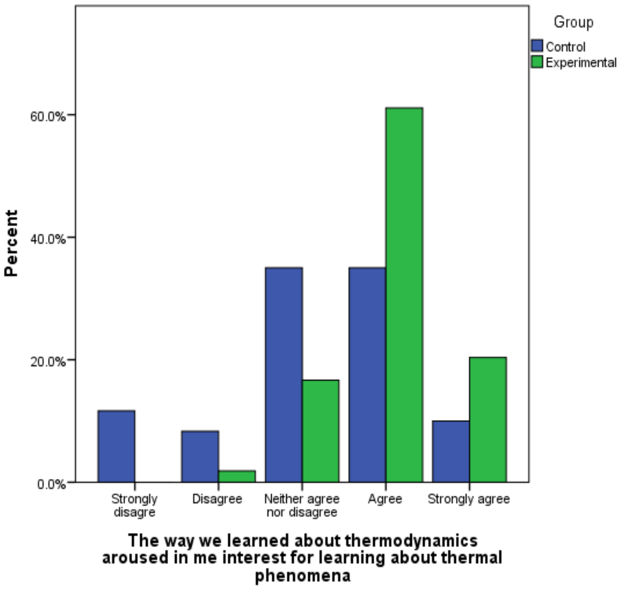

Figure 1: Treatments' effects on students' interest

Between-group differences in students' general impression about the teaching treatments are presented in Figure 2.

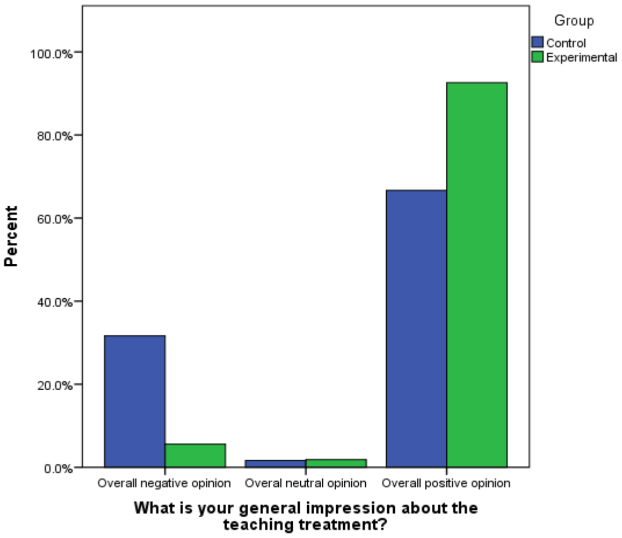

Figure 2: General impression about the teaching treatment

Finally, Figure 3 shows how students from the experimental group felt about the idea of learning about other physics topics by using an approach similar to the one used in learning about thermodynamics.

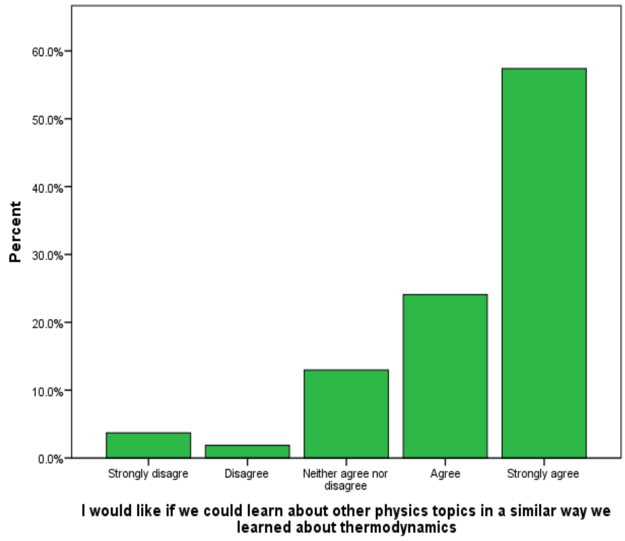

Figure 3: Students' interest for learning other topics by using a context-rich approach

Specifically, 90.3% of girls and 69.6% of boys from the experimental group expressed their interest (i.e., they agreed or strongly agreed with the statement) in continuing learning physics by using a context-rich approach.

DISCUSSION

The results of our study show that the level of students' understanding of thermal phenomena was very low at the pretest. This indicates that students enter the high school with many misconceptions about heat and temperature which is in line with the findings by Mešić (2012). Furthermore, from results of the posttest it follows that none of the treatments was effective in promoting conceptual change.

Although, the students from the control group were slightly more successful on posttest, the analysis of covariance showed that the observed between-group differences in conceptual understanding were not statistically significant. This finding supports the conclusion that context-rich approaches are most often equally effective as traditional instruction (Bennet, Lubben, Hogarth, 2006). Furthermore, results from Table 3 indicate that context-rich approaches are more effective for girls than for boys.

When it comes to students' ratings of the teaching treatments, firstly it is useful to note that the context-rich approach aroused in students a much higher level of interest about thermal phenomena compared to the traditional approach. Students' ratings were consistent for all three items. They not only reported a higher level of interest for learning, but also a more positive overall opinion on the delivered instruction. More than 80% of students from the experimental treatment stated that they would like to continue learning physics through a context-rich approach. Thereby, it seems that context-rich approaches have a particularly positive effect on girls' interest in science – approximately 90% of girls compared to 70% of boys from the experimental group stated that they would like to continue to learn through the context-rich approach. Our findings on the attitudes towards thermodynamics instruction support the idea that context-rich approaches are effective when it comes to improving attitudes towards science (Key, 1998; Yager and Weld, 1999; Barber, 2000). Furthermore, Smith and Matthews (2000) also found that context-based/science-technology-society approaches particularly promote girls' interest in science.

The results of our study suggest that effectiveness of learning in context-rich approaches depends on the level of aroused interest, as well as on the structuredness of the learning activities. As a matter of fact, it seems that in the experimental approach the activities aroused a higher level of interest in girls than in boys which led to a higher level of engagement and learning outcomes in girls. On the other hand, it seems that the complexity of real-world problems may induce cognitive overload in novices (Kirschner, Sweller, Clark, 2006). Thus, although having a higher level of interest, students from the experimental group did not succeed in developing a logically coherent network of knowledge and eventually both treatments proved to be equally effective. It is well known that for teachers it is often difficult to choose/design real-world problems whose structure is compatible with the logical structure of the corresponding scientific discipline (Mueller, 2006).

A potential limitation of this study is related to the fact that students from the experimental group were not provided with worksheets that could have guided them more closely through their learning activities.

CONCLUSION

In this study we aimed to investigate how teaching thermodynamics through a context-rich approach affects conceptual understanding and interest for science in high-school students.

Our conclusions are as follows:

Most often, context-rich approaches are equally effective as traditional instruction when it comes to developing conceptual understanding in science (see Bennet, Lubben, Hogarth, 2006).

Most often, context-rich approaches are more effective than traditional instruction when it comes to arousing students' interest in science (Yager and Welden, 1999; Barber, 2000; Key, 1998).Often context-rich approaches are more effective for girls than for boys (Smith and Matthews, 2000; Bennet, Lubben, Hogarth, 2006).

Effectiveness of context-rich approaches depends on the level of aroused interest, as well as on the structuredness of learning activities. When using context-rich approaches, teachers have to carefully manage students' cognitive load (Kirschner, Sweller, Clark, 2006).

In our future studies we are going to investigate different ways of managing cognitive load in science classrooms that implement context-rich approaches.

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Appendix

A brief description of posttest items is provided in Table 4.

Table 4: Brief description of posttest items

Item 1	**Item 2**	**Item 3**	**Item 4**	**Item 5**	**Item 6**
Measuring temperature	Heat capacity of water	Reflection of thermal radiation	“A sweating” glass bottle	How a bulb influences entropy?	Hand above a flame
Item 7	**Item 8**	**Item 9**	**Item 10**	**Item 11**	**Item 12**
How does air/water at 20 °C feel?	Temperature of metal vs wood	Isochoric process	Isothermal process	Isobaric process	Thermal energy of iceberg vs cup of water
Item 13	**Item 14**	**Item 15**	**Item 16**	**Item 17**	**Item 18**
Cooling of metal plate and cookies	Heat conductors vs isolators	Can work affect temperature?	Melting of ice wrapped in paper	How a fan cools us down?	Heating already boiling water
Item 19	**Item 20**	**Item 21**	**Item 22**	**Item 23**	**Item 24**
Cooking on a mountain and in valley	Air humidity and evaporation	Fan in an isolated room	Interpreting p-V diagram - heat	Interpreting p-V diagram - work	Is this heat pump/engine possible?
Item 25	**Item 26**	**Item 27**			
Is this heat pump/engine possible?	Is this heat pump/engine possible?	Is this heat pump/engine possible?			

Summary/Sažetak

Rezultati ranijih istraživanja pokazuju da kod učenika svih uzrasta postoje mnoge miskoncepcije o toplotnim pojavama. Često su te miskoncepcije uzrokovane nerazlikovanjem značenja pojmova u jeziku struke i jeziku svakodnevnice. Studija predstavljena u ovom radu imala je za cilj istraživanje efekata obogaćivanja tradicionalne nastave termodinamike sa kvalitativnim i kvantitativnim primjerima iz svakodnevnog života. U tu svrhu proveden je predtest-posttest kvazi-eksperiment koji je uključivao 114 učenika srednjih škola (uglavnom petnaestogodišnjaka) raspoređenih u čeitiri podgrupe. Dvije podgrupe (n=60) podvrgnute su tradicionalnom tretmanu, dok se u preostale dvije podgrupe (n=54) implementirala nastava termodinamike situirana u autentične kontekste. Rezultati analize kovarijanse pokazali su da nema statistički značajnih međugrupnih razlika kada je u pitanju uticaj tretmana na konceptualno razumijevanje termodinamike. Međutim, nastavni pristup zasnovan na obradi gradiva u autentičnim kontekstima bio je mnogo uspješniji po pitanju razvijanja učeničkog interesa za prirodne nauke. Nivo interesa pobuđen ovim pristupom bio je znatno viši kod djevojčica nego kod dječaka.