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Seeking the right balance between three teaching approaches: a quasi-experimental study in the context of learning about thermal phenomena

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Abstract: In this study, we investigated which teaching approach may be optimal to facilitate learning about thermal phenomena in primary school. Concretely, we conducted a pretest-posttest quasi-experiment that included 45 eighth-grade students divided into three groups. In the first group (a non-interactive teacher-centered approach), the teacher gave an experiment-based lecture on converting thermal energy into mechanical work. In the second group (a teacher-centered interactive approach), the teacher gave the same experiments-based lecture, but interacted much more with the students and encouraged them to think about the demonstrations. Finally, in the third group, the student-centered interactive approach was applied. The results of the ANCOVA showed that the three teaching approaches were equally effective in developing students' understanding of thermal phenomena. However, closer analyses showed that students who learned from the teacher-centered interactive approach significantly outperformed their peers when it came to understanding basic thermal concepts approach, students worked in small groups to conduct the same experiments and "discover" the same relationships that the teacher had introduced in the previous one.

INTRODUCTION

Understanding thermal phenomena and thermodynamics is an important aspect of scientific literacy and this topic has found its place in science curricula at all educational levels. It is well known that many students have difficulty, understanding the basic concepts of thermal phenomena and thermodynamics (Vidak, Odžak & Mešić, 2019, Erickson, 1979, Carlton, 2000, Clough & Driver, 1985, Tiberghien's, Chu, Treagust, Yeo and Zadnik, Lewis (1996). In order to effectively overcome students' misconceptions, it is necessary to make additional efforts in the processes of conceptualization and conceptual change and therefore it is of great importance to design teaching lectures that will facilitate a better understanding of these phenomena. The literature shows that there is no consensus on which teaching approach is most useful in all physical contexts, so it is very important to determine the best approach for different contexts. One of the ways we can improve traditional teaching (a non-interactive teacher-centered approach) is to conduct experiments. In this approach, we can direct students closer to the theory and motivate them in studying physics phenomena. When performing the experiment, we can use the predict-observe-explain technique and predict-explain-observe-explain technique to foster conceptual understanding. The predict-observe-explain technique implies that students predict what will happen before performing the experiment, then observe what will happen and finally the students together with the teacher through a discussion come to an explanation of the observed phenomenon.The predict-explain-observe-explain technique consists of one additional element that is reflected in students explaining why they think what they predicted will happen even before the experiment is performed. Many studies have shown that research-based teaching (a teacher-centered interactive approach) can help students to increase their level of conceptual understanding and gain a positive attitude toward science (Akar, 2005; Coulson, 2002; Tinnin, 2001). In the research of conceptual abilities using the CSEM test, students taught with the investigative teaching achieved higher results on the posttest i.e. students of four different lecturers achieved a score between 63% and 74%, while the average for their level of education was 47% (Etkina i Van Heuvelen, 2007). Furthermore, a comparative study conducted in 2004 showed that students taught by the investigative teaching method achieved 15% higher results than students taught by a non-interactive teacher-centered approach (73% of correct answers compared to 58% of correct answers) (Etkina i Van Heuvelen, 2007). In general, when using any teaching method it is important to consider the influence of cognitive load. Teachers often place high demands on working memory resources resulting in poor ability of students to learn the given materials. The working memory resources needed to learn a particular material (Sweller and Chandler, 1994) or to perform a particular task (Sweller et al., 1998) represent a cognitive load. The total cognitive load is equal to the sum of the intrinsic, relevant, and irrelevant cognitive load (Pass, Tuovinen, Tabers & Van Gerven, 2003). The relevant cognitive load leads to the adoption of new knowledge and automation of existing ones, as well as to the expansion of existing knowledge structures. By optimizing the intrinsic and minimizing the irrelevant cognitive load, the conditions for maximum student productivity are achieved. To achieve this goal (Van Merrienboer & Sweller, 2005) stated that it is useful to divide lectures into smaller "pieces" and provide explicit clues as well as to use external visualizations and analogies. Hardiman, Pollastek & Ewil (1986) and Brown & Campione (1994) stated that students who learn through investigative teaching with minimal feedback often become lost and frustrated, and their confusion can lead to misconceptions. Moreno (2004) concludes that there is a growing number of research showing that students learn with more understanding when investigative teaching is a more teacher-centered approach. In our study, we used all the scientific recommendations to balance the cognitive load of students and direct their attention to the optimal understanding of given thermodynamic phenomena.

Aim of the present study

The aim of our study is to investigate students' conceptual understanding of the transformation of the inner energy into work, as well as the effects of different teaching approaches (teacher-centered interactive approach and student-centered interactive approach) compared to a non-interactive teaching teacher-centered approach. The results of methodological research in Bosnia and Herzegovina indicate that the interactive instruction approach is not sufficiently used (Suzić et al., 2009). The significance of this research is reflected in the fact that we will compare the achievement of a non-interactive teacher-centered teaching with two approaches of interactive teaching in developing a conceptual understanding of the transformation of internal energy into work and influence of individual teaching approaches to the aimed area. The results of this research can serve to improve the quality of interactive teaching implementation in the field of heat phenomena.

METHODOLOGY

Research design

In order to investigate the effectiveness of different teaching approaches, a quasi-experimental research was conducted as part of the regular classes determined by the curriculum. The total sample of students consists of three classes. One week before the start of the treatment a pretest was conducted. The pretest consisted of ten conceptual multiple choice questions that reflected the students' misconceptions about the material relevant to the successful learning of the lecture "Turning internal energy into work". Seven days after the treatment, a posttest was conducted in which we measured the conceptual understanding of converting internal energy into work (closed-relevant conceptual questions) and elemental conceptual questions relevant to understanding the conversion of internal energy into work (broadly-relevant conceptual questions). To conduct pretest and posttest we allocated 25 and 35 minutes.

Participants

This study included 45 eighth-grade primary school students from the Primary School "Nova Bila" in Nova Bila, Bosnia and Herzegovina, of whom 20 were male and 25 female. The curriculum of the course includes that students learn about internal energy and heat in a two-hour lecture that is situated in the second semester of the school year. The total sample of students consists of three classes. One class received non-interactive teacher-centered treatment, while the remaining two received two different versions of the interactive teaching approach.

Curriculum and teaching treatment

In our research, quasi-experimental study was conducted as part of the regular class determined by the curriculum. Students in all three eighth grade classes were in their natural environment. When creating lectures, special accent was put on the content and conceptual questions. The questions in the introductory part of the lecture, experiments and the accompanying explanations, and the final part of the lecture were synchronized in all three groups. The questions from the pretest and posttest were not directly addressed during the treatment, but a theoretical basis for understanding these questions through the contents of the main part of the lecture was provided. It is well known that teacher-centered non-interactive teaching approach is characterized by one-way communication. Accordingly, the department taught in the teacher-centered non-interactive approach was characterized by one-way communication. The researcher solely performed a repetition of the relevant material, as well as the implementation of the main and final part of the lecture. In the class taught by teacher-centered interactive approach teaching students were interactively involved in the teaching process. The repetition of relevant material was conducted through conversation with students, the experiments were performed using the predict-explain-observe-explain technique and the final part of the lecture was conducted through the questions which the researcher posted to the students. The third class was divided into four groups. The groups were composed of students of different abilities, according to the results of the pretest. Students conducted part of the lecture in independent activities, and the other part interactively with the researcher. The introductory part of the lecture was implemented through a conversation, after which the students were focused on group work. The group work has been conducted using the pre-created worksheets and experimental kit according to which students were guided step by step to the final explanation. After the students come to the final explanation of the outcome of the physical experiment through group work, the researcher explains it once again through a conversation with all the students. The final part of the lecture was conducted through a conversation between the researcher and the students.

RESULTS AND DISCUSSION

a) Analysis of the pretest scores

Within the group taught by teacher-centered non-interactive approach (TNI), there were 12 participants (Male=4, Female=8), 18 participants were taught by a teacher-centered interactive approach (TI) (Male=10, Female=8) and 15 (Male=6, Female=9) were student-centered interactive (SI). The pretest results show that the mean value of the TNI-group, TI-group and SI-group was 2.83 (1.46), 3.67 (1.84) and 3.40 (1.50), respectively, while the maximum score that students could achieve in the pretest was 10. The minimum score achieved in the TNI-group was 1, while maximum was 5; minimum score achieved in TI-group was 0, while maximum was 6; minimum score achieved in SI-group was 0, while maximum was 5. Table 1 shows the summarized data. The conceptual questions in the pretest reflect the content of the chapter “Internal energy and heat” in the regular curriculum. According to the results, students have a lot of difficulties in understanding thermodynamic concepts. According to the data in Table 2, we can conclude that students’ scores on many questions are below 50 % for each group. Scores on Q1, Q2, Q5 and Q9 are very low for each group. The questions Q1, Q2, and Q5 relate to heat transfer from one object to another, while question Q9 relates to the particle movement in a closed container. The cause of the low scores on questions Q1 and Q5 can be attributed to the fact that students relied on their sensory experiences. Accordingly, students for objects that feel colder claim to be at a lower temperature and conclude that the insulator between two objects act as a heat source. Numerous students answered the question Q1 claiming that the metal would have the lowest temperature (TNI=83.3%, TI=77.8% and SI=86.7%). Question Q2 identified eventual misconception within the physics language and terminology, which is closely related to the heat transfer. To this question, most students replied that coldness is transferred from water to eggs (TNI=66.7%, TI=77.8% and SI=86.7%). As mentioned earlier, research by Chu, Treagust, Yeo and Zadnik (2012) found that students observe a sweater as a heat source rather than a thermal insulator, as confirmed by our research. It is interesting to emphasize that the question Q6 identified an identical misconception in a different context and that groups TI and SI were more successful with this question. Finally, all groups were equally unsuccessful on question Q9. Numerous students chose answer D (TNI=41.2%, TI=50% and SI=40%) as the correct answer i.e. the particle trajectory is circular.

Table 1. The pretest achievements

	Number of participants	Male	Female	Mean value (standard deviation)	Minimum value	Maximum value
TNI-group	12	4	8	2.83 (1.46)	1	4
TI-group	18	10	8	3.67 (1.84)	0	6
SI-group	15	6	9	3.40 (1.50)	0	5

Table 2. Summary of the individual groups scores on the pretest

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10
TNI-group	16.7%	16.67%	33.3%	83.3%	16.7%	16.7%	16.7%	33.3%	16.7%	33.3%
TI-group	11.1%	16.67%	72.2%	72.2%	16.7%	33.3%	55.6%	66.7%	11.1%	11.1%
SI-group	6.7%	6.7%	66.7%	73.3%	13.3%	33.3%	20.0%	73.3%	13.3%	40.0%

Between-group differences are presented in the following two figures. The x-axis shows the percentage of students who achieved the score presented on the y-axis.
Figure 1 shows between-group differences on the pretest for the teacher-centered non-interactive group and the teacher-centered interactive group.

We can notice the significant deviation in the number of students who have score 4 in different groups. Furthermore, 11.1% of students have score 0 in the teacher-centered interactive group while in the teacher-centered non-interactive group there were no such students.

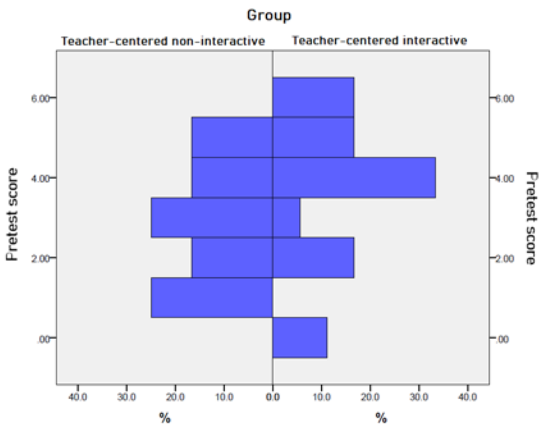


Figure 1. Between-group differences for teacher-centered non-interactive and teacher-centered interactive groups. The maximum score was 10.

If we compare the teacher-centered non-interactive and the student-centered interactive group (Figure 2), we can notice a deviation in some categories for the students from the SI group. We can see from the Figure 2 that 6.7% of students achieved a score 0 from the SI group, while there were no students with such score in the TNI group.

Furthermore, 25% of the students from the TNI group achieved score 1 on the pretest, while in the SI group the percentage was 0. Score 2, 4 and 5 on the pretest were achieved by 16.7% of the students from the TNI group while that percentage in the SI group was 26.7%, 33.3%, and 26.7%, respectively. If we consider the mean value, we can notice that there is no significant variation between groups and we cannot emphasize an overlap based on the test scores.

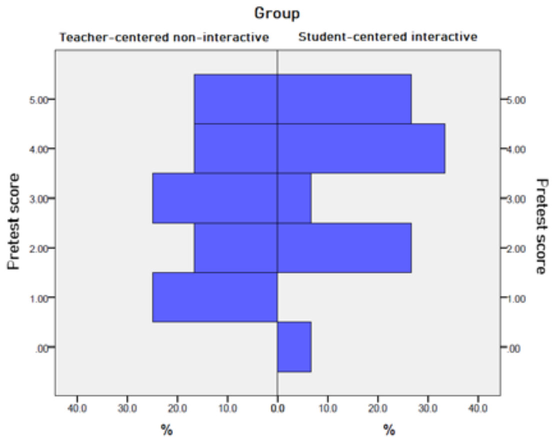


Figure 2. Between-group differences for teacher-centered non-interactive and student-centered interactive groups on the pretest. The maximum score was 10.

For the homogeneity of the variance on the pretest, we conducted Levene's test where the significance value was $p=.728$ ($p>0.05$). Accordingly, we can conclude that there is no significant variation between the group's variance achieved on the pretest.
We used the Kolmogorov-Smirnov test to check normality of the distribution. For the TNI-group, TI-group and SI-group significances were $p=0.200$, $p=0.008$ and $p=0.010$, respectively. Since the significance for the TI group is $p=0.008$ ($p<0.05$) we can conclude that the distribution varies from the normal one. We used Kruskal-Wallis's test whose significance was $p=.309$, from which we can conclude that there is no statistical significance between groups on the pretest. Table 3 shows between-group differences on the pretest scores.

Table 3. Between-group differences on the pretest scores

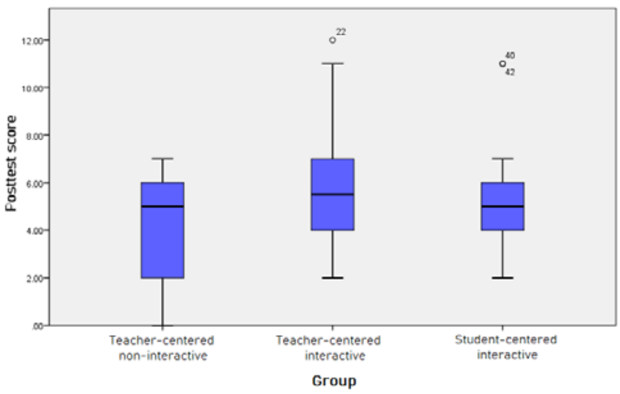
(I) Group	(J) Group	Significance
Teacher-centered non-interactive	Teacher-centered interactive	.370
Teacher-centered interactive	Student-centered interactive	.888
Student-centered interactive	Teacher-centered non-interactive	.649

b) Analysis of the posttest scores

The posttest consisted of fourteen questions, three of which had a multiple sub-questions. All questions were conceptual questions divided into two main groups: closely relevant and broadly relevant questions. Broadly-relevant questions measured the knowledge needed to conceptually understand the target lecture, while closely-relevant questions were closely related to the conversion of internal energy into work. It is important to know that none of the questions from the pretest were on the posttest.

Boxplot diagram in the Figure 3 shows that the median in the teacher-directed interactive group is slightly higher compared to medians in the other two groups (by 0.5). The median for the teacher-centered non-interactive and student-centered interactive group is equal and amounts to 5.00. Score intervals for teacher-centered non-interactive, teacher-centered interactive and student-centered interactive groups are 7.00 (min=.00. max=7.00), 10.00 (min=2.00, max=12.00) and 9.00 (min=2.00, max=11.00), respectively.

Figure 3 Score distribution on the posttest



Furthermore, Figure 4 shows the boxplot diagram for different genders. We can notice that the median is higher for boys in the first two groups, while the median for girls is higher in the student-centered interactive group.

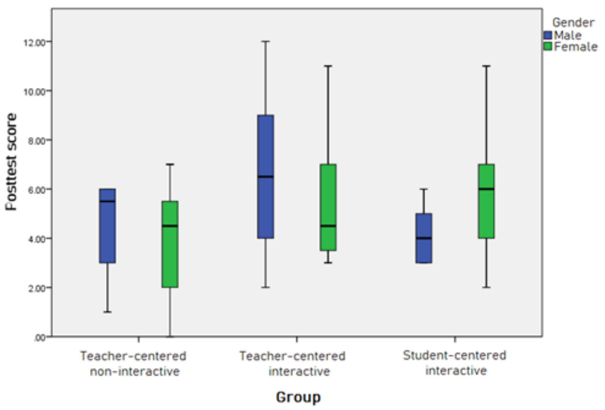


Figure 4. Score distribution according to gender

Table 4 shows the total score S, mean value (MV), standard deviation (SD) and variance (V) in each group, for closely relevant (CR) and broadly relevant (BR) questions, as well as the total value for each question on the posttest. We can immediately notice that the mean value is the highest for the teacher-centered interactive group and amounts to 6.12, for the student-centered interactive group the mean value is 5.40, while for teacher-centered non-interactive it is the lowest and equals to 4.08. Furthermore, we can observe the same order of groups when it comes to the mean value within broadly relevant questions. However, the mean value for closely-relevant questions for the student-centered interactive group is 2.73, for the teacher-directed group is 2.56, and for the teacher-centered non-interactive group is 2.08. We can conclude that the mean value of the scores for the experimental groups for each of the categories is higher than the mean value of scores for the teacher-centered non-interactive group.

Table 4. Scores on the posttest

	Teacher-centered non-interactive group		
	CR	BR	S
MV	2.08	2.00	4.08
SD	1.16	1.60	2.27
V	1.36	2.54	5.17
	Teacher-centered interactive group		
	CR	BR	S
MV	2.56	3.56	6.12
SD	2.38	1.29	2.89
V	5.67	1.67	8.34
	Student-centered interactive group		
	CR	BR	S
MV	2.73	2.67	5.40
SD	2.05	1.05	2.64
V	4.21	1.10	6.97

We can gain a deeper insight into student's progress by considering the score difference on the pretest and the posttest. Since there were ten questions on the pretest, while there were fourteen on the posttest, we perform the scaling of the results by multiplying the pretest score with the factor of 1.4. After that, we performed the following coding: students who scored 0 to 2.8 were put in the low-ability group (L), students who scored 2.8 to 5.6 were put in the medium-ability group (M), and the students who scored 5.6 to 8.4 were put in the high-ability group (H). After scaling and placing the students in their respective ability groups, we measured the score difference on the pretest and posttest, which is summarized in the following table 5.

Table 5. Mean values difference regard the ability groups

Ability level	Teacher-centered non-interactive
Low	1.84
Medium	-0.76
High	-2.00
	Teacher-centered interactive
Low	4.12
Medium	0.31
High	-0.87
	Student-centered interactive
Low	3.56
Medium	0.13
High	-2.25

We can notice that the average difference of the scores has a tendency to decrease for all groups. Based on this fact, the students from the low-ability group within the teacher-centered interactive group made the greatest progress, followed by students from the low-ability group within the student-centered interactive group, and finally the students from the low-ability group within the teacher-centered non-interactive one. We need to consider this fact with special care. Better insight into group differences could be achieved by using the same pretest and posttest to obtain highly valid considerations. The number of students is too small and there is a danger of the statistical inference (for example, statistically speaking, there is a higher probability for progress of a students who achieved a lower score on the pretest).

All previous considerations were based on the mean value of the scores achieved on the pretest and posttest. Now, we use inferential statistic to determine if there is statistically significant difference between groups. For this purpose, the analysis of covariance is used. Score on the pretest is used as a covariate, while the dependent variables are total pretest scores, followed by the scores on the broadly-relevant questions and, finally, the scores achieved on the closely-relevant questions. To better understand how the covariance (scores on the pretest) adjusts the original mean value and the standard deviation, we will refer to the tables 6 and 7.

Levene's coefficient for these data is .680, from which it is possible to conclude that variances of the score achieved in the posttest are homogeneous. By analyzing the between-group differences, with the posttest as a dependent variable, we determine that the difference between groups are not so statistically significant [$F(2,41)=1.719$, $p=.192$].

When we choose the posttest scores on the closely-relevant questions as a dependent variable, Levene's coefficient is .042, which could mean that the results are less reliable. When it comes to the analysis of the covariance, we conclude that there is no statistically significant difference between the presented groups [$F(2,41)=.351$, $p=.706$].

Table 6. Mean values on the posttest, closely-relevant and broadly-relevant questions. Standard deviations are given in parentheses.

Mean value	Posttest	Closely-relevant questions	Broadly-relevant questions
Teacher-centered non-interactive	4.083 (2.275)	2.083 (1.164)	2.000 (1.595)
Teacher-centered interactive	6.111 (2.888)	2.556 (2.382)	3.556 (1.294)
Student-centered interactive	5.400 (2.640)	2.733 (2.052)	2.667 (1.047)

Table 7. Adjusted mean values on the posttest, closely-relevant and broadly-relevant questions. Standard deviations are given in parentheses.

Adjusted mean value	Posttest	Closely-relevant questions	Broadly-relevant questions
Teacher-centered non-interactive	4.173 (.783)	2.079 (.597)	2.094 (.377)
Teacher-centered interactive	6.058 (.635)	2.558 (.484)	3.500 (.306)
Student-centered interactive	5.392 (.690)	2.734 (.526)	2.659 (.333)

Finally, we select broadly-relevant questions as the dependent variable. The Levene's coefficient is equal to .061, which is not statistically significant and we can conclude that the variances are homogeneous. Here we obtain a statistically significant difference between the groups [$F(2,41)=4.343$, $p=.019$]. Since we find statistically significant differences between some groups, we need to conduct post hoc testing. Using the Bonferroni test, a statistically significant difference was found between the non-interactive teacher-centered and the teacher-directed interactive group ($p=0.20$).

Therefore, a statistically significant difference is determined between the teacher-centered non-interactive and the teacher-centered interactive groups in the domain of the broadly-relevant questions. In terms of achievement on the posttest, closely-relevant, and broadly-relevant questions, there are no statistically significant differences among groups, with regard to gender.

By analyzing the pretest, we perceive a poor understanding of the basic concepts of thermodynamics. During the treatment, the lecture "Converting internal energy into work" was processed in a way that the curriculum was simplified and after that, the experiment was conducted with students. On the theoretical side, we can say that students studied by manipulating existing knowledge to gain more complex knowledge. Since most students did not have a well-developed knowledge to understand the complex material (Converting internal energy into work), it was expected that they would not sufficiently develop the coherent structures of knowledge. Instead, students adopted more fundamental knowledge during the treatment. Statistically speaking, the teacher-centered interactive group achieved a statistically significant difference when it comes to the basic thermodynamic concepts, compared to students taught in a non-interactive teacher-centered approach.

During the student-centered interactive physics teaching, students conduct most of the activities independently, which could be the reason for the poor understanding of the lecture “Converting internal energy into work”. Students tried to gain some insight into more complex aspects by using the knowledge they already had, but as they did not have a sufficiently developed knowledge, it was expected that they did not sufficiently understand the new lecture. The student-centered interactive teaching method would probably be more effective if we use more time to implement it, which is in line with the fact that this type of teaching takes more time than the teacher-centered non-interactive teaching method.

CONCLUSION

The goal of this study was to compare the effectiveness of two types of interactive teaching compared to traditional teaching. To accomplish this goal, we conducted research in which we measured students' conceptual understanding of basic thermodynamic concepts in the pretest, and conceptual understanding of thermodynamic concepts (broadly relevant questions) and converting internal energy into work (closed relevant questions) on the posttest. Three eighth-grade classes participated in the study, with one department being taught in the teacher-centered non-interactive, the other as teacher-centered interactive, and the third through student-centered interactive approach.

It is very important for different groups of students in different contexts, to investigate what is the relationship of time spent on what will lead to the best learning of selected topics. In this study, we examined this relationship for eighth grade’ students from Bosnia and Herzegovina in the context of learning about converting internal energy into work. The obtained results show that the least effective was the teacher-centered non-interactive approach. These results can be related to the fact that in this approach students are not encouraged to implement higher thought processes, i.e. time is not used effectively to facilitate learning. On the other hand, a student-centered interactive approach has many advantages to foster higher thought processes, but many students have difficulty managing the entire learning process independently, which can lead to cognitive overload. The teacher-centered interactive approach seems optimal for the age of students who are just beginning to learn physics - this approach seems to offer optimal balance through timely class discussions.

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Summary/Sažetak

U ovoj smo studiji istražili koji nastavni pristup može biti optimalan za olakšavanje učenja o toplinskim pojavama u osnovnoj školi. Konkretno, proveli smo kvazi eksperimentalno istraživanje koje je obuhvatilo 45 učenika osmih razreda podijeljenih u tri skupine. U prvoj skupini (ne-interaktivni pristup usmjeren na nastavnika), nastavnik je održao predavanje sa eksperimentima o pretvaranju toplinske energije u mehanički rad. U drugoj skupini (interaktivni pristup usmjeren na nastavnika) nastavnik je održao isto predavanje temeljeno na eksperimentima, ali je mnogo više komunicirao sa učenicima i potaknuo ih da razmišljaju o predstavljanim eksperimentima. Konačno, u trećoj skupini (interaktivni pristup usmjeren na učenika) učenici su radili u malim skupinama kako bi izveli jednake eksperimente i „otkrili“ odnose koje je nastavnik uveo u prethodne dvije skupine. Rezultati ANCOVA-e pokazali su da su jednaku učinkovitost sva tri nastavna pristupa u razvijanju razumijevanja učenika o toplinskim pojavama. Međutim, detaljnije analize pokazale su da učenici koji su učili korištenjem interaktivnog pristupa usmjerenog na nastavnika značajno nadmašuju svoje vršnjake kada se promatra razumijevanje osnovnih toplinskih pojmova.