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High-School Students Believe School Physics Helps in Developing Logical But not Creative Thinking: Active Learning Can Change This Idea

Mirko Marušić[1]
Josip Sliško[2]

[1]*University of Split, The Faculty of chemistry and technology, Teslina 10, 21000 Split, Croatia*
mirko@marusic.info

[2]*Benemerita Universidad Autonoma de Puebla, Apartado Postal 1152 Puebla C.P. 72000, Mexico*

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Abstract
This study is based on two exploratory questions with the aim of determining the relative effectiveness of two different student activities, called *Reading, Presenting and Questioning* (RPQ) and *Experimenting and Discussing* (ED), in changing students' perceptions and attitudes about the impact of physics learning on the development of logical and creative thinking. One-semester of data from this high school project for RPQ group (91 students) showed a shift of 11% in their attitudes related to the development of logical thinking, while student attitudes about the development of creative thinking showed a shift of 20.9%. The results for the ED group (85 students) showed a considerable shift in positive attitudes about the role of physics in the development of logical thinking of 31.7% while student attitudes towards the development of creative thinking made a significant progress of 36.4%. These results indicate that both forms of active learning improve student perceptions about the impact of teaching physics on the development of logical and creative thinking, although students in ED group show much bigger improvements.
Keywords: Reading, Presenting and Questioning method; Experimenting and Discussion method; Logical thinking; Creative thinking.

Introduction

Actual pedagogical approaches support the idea that teaching can be realized in a variety of ways acceptable for students, respecting their individual styles and dynamics of learning, without neglecting the basic goals and tasks of education. Such modern school, striving to be liberal, open and creative, replaces a rigid curriculum with a more flexible one, putting students at the centre of the educational universe, taking into account their needs, abilities and interests (Renzulli & Reis, 1997; Renzulli, 1999). Therefore, it is reasonable to raise a question of the ways and possibilities of encouraging creative thinking in the contemporary school. Nevertheless, it is not an easy task since years of moulding the individual according to the existing educational routines significantly complicate the process (Huitt, 2009).

Although there are several definitions of creativity, there is a widely accepted description which defines it as a process that leads to new and appropriate ideas (Sternberg & Lubert 1999). In other words, creativity is not only limited to the divergent thinking or the ability to create something unusual. In scientific thinking, it requires additionally an ability to evaluate and choose between competing ideas (Reiter-Palmon & Illies, 2004).

A successful development of ideas that are useful for problem solving within a specific area requires a substantial amount of specific knowledge and skills to apply this knowledge in a flexible way (Csikszentmihalyi, 1997). Unfortunately, despite the unquestionable social need to increase the number of creative thinkers, the test results of creative thinking show that this type of thinking has been steadily declining, especially among primary school children (Kim, 2006).

Numerous teaching methods and curricula have been developed to meet all aspects of standard physics courses. Most of them are based on constructivism (Jonassen & Land, 2000), which emphasizes students' active role, their interaction with the environment and interpretation of information in relation to their previous experience (Trowbridge et al., 2000).

Physics programmes that include alternative problems and group work are *Problem-Based Learning* (Duch et al., 2001) and *Cooperative Group Problem Solving* (Heller et al., 1992). Other classroom teaching strategies that also involve teamwork and cooperative learning are *Physics by Inquiry* (McDermott et al., 1996), *Tutorials in Introductory Physics* (McDermott et al., 2002), *Workshop Physics* (Laws, 1991), *Studio Physics* (Sorensen et al., 2006), *Investigative Science Learning Environments* (Etkina & Van Heuvelen, 2007), *SCALE-UP* (Beichner et al., 2007), and *TEAL* (Dori & Belcher, 2005).

Despite the research undertaken and efforts invested in the development of curricula, physics teaching at the vast majority of faculties has remained the same (Yerushalmi et al., 2010). Consequently, students' misconceptions about the physics concepts, principles and theories are highly present, and are often manifested in the lack of a deeper understanding of physical phenomena and are often in conflict with the accepted scientific concepts (McDermott & Redish, 1999). There is a series of evidence showing that students use coherent mental models, which activate only partial knowledge (Hammer, 2000; Redish, 1999).

Besides the attention paid to developing students' cognitive abilities in physics, a significant area of research activity exists that is focused on researching students' expectations of physics, epistemological beliefs about what makes learning a science, both generally and with special reference to physics (Redish et al., 1998). Student beliefs and epistemology are worth studying because they affect students' behaviour and learning when new teaching strategies are implemented (Hammer & Elby, 2002).

Well-known surveys for probing student beliefs about the physical sciences and their learning, like MPEX (Redish et al., 1998), VASS (Halloun & Hestenes, 1998), EBAPS (White et al., 1999), and CLASS (Adams et al., 2006), insufficiently analyse the aspect of students' attitudes towards the creativity of science itself and a possible influence of science learning on development of students creativity. The research conducted so far indicate that the dominant attitude is generally related to the fact that science is not creative (Masnick et al., 2010; Newton & Newton, 2010). A significant number of students and teachers see creativity as a general ability present primarily in the context of artistic activity (Newton & Newton, 2009; Diakidoy & E. Kanari, 1999).

However, a series of teaching interventions have been developed with the aim of changing both students' and teachers' attitudes about physics classes as well as increasing the presence of creativity in teaching science (Hu et al., 2013; Mahboub et al., 2004). Engaging students in scientific processes, like formulating and testing explanations of scientific phenomena, are promising strategies in increasing number of opportunities for creative thinking in school settings (Russ, 2008; Etkina & Van Heuvelen, 2007). Other active learning methods, like learning physics through explicite modeling (Wells et al., 1995), might likely have similar effects.

Since students' previous experience of learning physics is relevant for the creating their attitudes about physics and learning physics as well as for the strength of these attitudes, it is reasonable to address the problem more extensively at the high-school level.

The goal of this research is to investigate how two different "learning packages", *Reading, Presenting, and Questioning* (RPQ) and *Experimenting and Discussing* (ED), alter students' perceptions of the potential impact of school physics on the development of their logical and creative thinking. The term "learning packages" stands for a combination of learning/teaching methods and a set of topics that is addressed by this method.

Study design

General information

The study was conducted with 6 classes (natural groups, formed by females and males) of senior high school students (17 – 18 years) in Split (Croatia) during spring semester of 2009.

This period is particularly suitable for conducting the project because students are in the last semester of their high-school education and already possess knowledge from different scientific areas as well as attitudes towards them.

The total number of students was 176 and they studied a classical and language-oriented curriculum. Although the study programme is language-oriented, students may decide to attend different courses at university level: from humanities to scientific and technical studies. In the Republic of Croatia there is no major difference between different high-school programmes. They all try to prepare students for a vast area of university study programmes. Namely, students are given the opportunity to find their real field of interest which often changes in the period of the four high-school years. Therefore, the curriculum also includes science subjects, such as biology, physics, and chemistry, which are present in the curriculum with two lessons per week, throughout four-year high-school education.

Details of the curriculum of language and grammar high school as well as the curriculum of the four years of high school physics teaching is given elsewhere (Marušić & Sliško, 2012a, 2012b).

It should be noted that students who participated in this study were in their sixth year of physics classes (two years in the last two years of elementary school and four years in high school). Physics in Croatian elementary and secondary schools is mainly characterized by the traditional form of teaching that lacks laboratory exercises and experiments.

Within the obligatory physics curriculum for the last year of gymnasium, there is some time, limited to one 45-minute session per week, allocated to free topic exploration. This means that, apart from the topics set by the syllabus, the teacher is allowed to introduce some additional ones that may reflect teacher's and/or students' interests. This free topic time was used for the research. In other words, a total number of 16 forty five - minute sessions (in the period of 16 weeks) were at the disposal for the project. These included 12 sessions for treating the chosen topics and 4 sessions for pre and post assessments. The topics were chosen by the researchers.

Pedagogical Methods

Reading, Presenting, and Questioning (RPQ)

RPQ pedagogy was applied to a group of three physics sections (91 students) by introducing some of the topics related to the recent scientific discoveries in physics in the following way:

(i) students' autonomous reading/study of popular articles suggested by the teacher–researcher,

(ii) reading/study of on-line resources, some obligatory and some discovered by the students themselves on the internet,
(iii) students' presentations of the learning results in PowerPoint™ format,
(iv) students' questioning about unclear elements of reading and peer-presented materials.

The rationale behind this design was derived from successful practices like 'read to learn" (Glynn & Muth, 1994), "present to learn" (Daley, 2004), and "question to learn" (Chin & Osborne, 2008). Two examples were chosen to illustrate the ways in which modern science has gained new knowledge:

1. Large Hadron Collider (LHC) at CERN
2. Wilkinson Microwave Anisotropic Probe (WMAP)

This teaching/learning design also involved breaking down each section into three different teams, with the purpose of encouraging discussion and further analysis of the suggested topics from the field of contemporary physics.

Experimenting and Discussion (ED)

ED pedagogy was applied to a group of three physics sections (85 students) who covered several classical physics topics in an active-learning way. As known from the previous studies, some of the sequential tasks which promote active learning are:

(1) Predict–Observe–Explain (White & Gunstone, 1992); or
(2) Observe–Explain–Predict–Test (Van Heuvelen & Etkina, 2006).

These physics learning sequences activate the existent students' knowledge and test it by comparing the predicted and the observed. These sequences of active learning were carried out by using simple experiments to treat a selection of physical phenomena for which students' alternative conceptions are well known (McDermott & Redish, 1999; Pfundt & Duit, 2006):

(a) Force and of motion (4 sessions)
(b) Pressure (hydrostatic, hydraulic, atmospheric, hydrodynamic) (4 sessions)
(c) Heat (4 sessions).

A detailed description of the curriculum, of the new teaching approaches and their implementation can be found elsewhere (Marušić & Sliško, 2012a, 2012b).

Gender characteristics of two groups and exploratory questions

The non-traditional methods described above were applied in a course of the academic year 2008/09 in the spring semester with the senior students (see Table 1).

Table 1. *Gender information for the observed groups*

	All students	RPQ group (Reading, Presenting and Questioning)	ED group (Experimenting and Discussion)
Females	110 (63%)	56 (62%)	54 (64%)
Males	66 (37%)	35 (38%)	31 (36%)
∑	176 (100%)	91 (100%)	85 (100%)

The aim of this study is to see how many students feel good in physics classes and who associate that feeling with a positive perception of developing their own logical and creative thinking. Our interest is, therefore, aimed at establishing that number and analyzing its change within the two observed groups.

In this study, we tried to answer the following research question:

How do the two different "learning packages", Reading, Presenting, and Questioning (RPQ) and Experimenting and Discussing (ED), affect the change of students' perceptions about the impact of school physics learning on developing their logical and creative thinking?

The study has focused on measuring only the change in students' personal perceptions of a potential relationship between learning school physics and development of logical and creative thinking.

Students' perceptions were measured prior and after the semester in which new learning experiences were obtained. The perceptions were determined by analysis of answers to two exploratory questions:

1. I feel good when I study physics because it helps me in developing logical thinking.
2. I feel good when I study physics because it helps me in developing creative thinking.

The form of the research instrument shows that we aim to analyze a specific group of students who feel good in physics classes, and among those students the ones who believe that «good feeling» is due the possibility to develop logical and creative thinking. It is clear that the students who feel bad as they learn physics and those who may feel well but do not see the connection between learning physics and development of logical or creative thinking will not agree with the offered exploratory questions. Although the latter combination of students' postures is logically possible and might be even seen as a deffect of the research instrument, we expected that the number of such students would be very small (in fact, our expectations were confirmed by the results) and unable to affect the research results.

The research was administered at the beginning of the semester (pre-test) and again in the last week of the semester (post-test). The students expressed their personal perceptions by choosing one option on a 5-point Likert scale:

I strongly disagree (graded as "-2"); I disagree (graded as "-1"); Neutral (graded as "0");
I agree (graded as "+1") and I strongly agree (graded as "+2").

The "positive perception" consists of both "I agree" and "I strongly agree".

As the construct that is sought through two exploratory questions of the research instrument is very complex, better tests, consisting of exploratory questions expressing only a carefully chosen single idea, will have to be developed in the future for its more detailed study. However, even this initial design of the research instrument enabled us to see that students understand the meaning of the offered exploratory questions and that they are interested in arguing their views.

In what follows, we will analyze the overall pre and post results of the answers to the two exploratory questions for each group. All evaluated students submitted valid pre and post tests, so all data is matched and represents 100% of the students in the courses.

Wilcoxon Signes Ranks Test was used for the statistical analysis of the data. It is a non-parametric statistical test used to compare two related samples or repeated measurings on the same sample (Siegel, 1956). Within the broader framework in which this study was carried out (Marušić & Sliško, 2012a), students were classified, according to the level of scientific reasoning, into the Concrete thinkers, Transitional thinkers and Formal thinkers. For this purpose the "Lawson's Classroom Test of Scientific Reasoning" (LCTSR) (Lawson, 1996) was used. In this study, we will analyze how students change their personal perceptions of the relationship between learning physics and development of logical and creative thinking, with regard to the levels of their scientific thinking at the beginning of the project.

Results and Analysis

We will first analyse the change in the percentage of students with positive attitudes towards the two exploratory questions. Pre and post percentages of students with a positive attitude are shown in Table 2. There are also shown the results by gender of students, as well as the percentage shift (Post-Pre).

Table 2 shows the results (Post-Pre) and the percentage shift for the observed groups of students by each exploratory question. At the same time, the results according to the gender of students are also shown.

Table 2. *Changes in the percentage of students with a positive attitude towards the exploratory questions (Post-Pre) for RPQ and ED group (Standard error in parentheses)*

		RPQ group (N=91) (Positive attitude)			**ED group (N=85)** (Positive attitude)		
Exploratory questions		Pre (%)	Post (%)	Shift (%)	Pre (%)	Post (%)	Shift (%)
1. I feel good when I study physics because it helps me in developing logical thinking.	Overall	67.0 (2.7)	78.0 (2.8)	**11.0** (1.6)	62.4 (3.1)	94.1 (0.9)	**31.7** (0.7)
	Females	75.0 (3.0)	82.1 (3.7)	**7.1** (0.8)	68.5 (2.9)	94.4 (1.1)	**25.9** (1.0)
	Males	54.3 (3.3)	71.4 (2.7)	**17.1** (1.2)	51.6 (4.1)	93.5 (1.3)	**41.9** (1.1)
2. I feel good when I study physics because it helps me in developing creative thinking.	Overall	26.4 (1.3)	47.3 (2.4)	**20.9** (1.2)	36.5 (1.6)	72.9 (1.1)	**36.4** (0.8)
	Females	26.8 (1.1)	48.2 (3.1)	**21.4** (1.6)	44.4 (3.7)	74.1 (1.0)	**29.7** (0.9)
	Males	25.7 (2.1)	45.7 (4.1)	**20.0** (1.0)	22.6 (4.0)	71.0 (2.3)	**48.4** (1.5)

* Large Shifts in Bold - p value <0.05

There is a statistically significant difference between RPQ and ED groups at the pre-test (see Table 2). For the first exploratory question, related to logical thinking, the students of the RPQ group show a significantly more positive attitude (67.0%) compared to the students of the ED group (62.4%). For the second exploratory question, related to creative thinking, more positive attitude (36.5%) is shown by the students of the ED group compared to the students of the RPQ group (26.4%).

There is a statistically significant difference in pre-results between the genders in the first exploratory question for the RPQ group and in both exploratory questions for the ED group. It should be emphasized that it is not completely clear why these differences occur. The pre-test results indicate that in both exploratory questions, the results of females are significantly higher than those given by the males (see Table 2). While the females of the RPQ group show the pre-test results of 75% (the first exploratory question) and 26.8% (second exploratory question), the males show positive perception in a percentage of 54.3% (the first exploratory question) and 25.7% (second exploratory question). In the ED group the females generate a pre-test score of 68.5% for the first exploratory question, and 44.4% for the second exploratory question, while males show 51.6% for the first exploratory question, and 22.6% for the second exploratory question.

At the post-test there is no statistically significant difference between the genders neither in the RPQ nor in the ED group. This would indicate that the males are progressing better than the females in both the RPQ and the ED group (except for the second exploratory question in the RPQ group). This change is also not completely clear and we require further study. After the project, both the females (7.1%) and the males (17.1%) of the RPQ show positive shifts for the first exploratory question, resulting in an overall positive shift of 11.0% (Table 2). For the second exploratory question, females and males show similar shifts (females 21.4%, males 20.0%), resulting in an overall positive shift of 20.9%. In the ED group females (25.9%), and males (41.3%), show positive shifts for the first exploratory question, resulting in an overall positive shift on the post-test of 31.7%. For the second exploratory question, a positive shift in post-test scores was is evident for both females (29.7%) and males (48.4%), which results in an overall shift of 36.4% for the entire ED group.

Result analysis regarding the students' level of scientific reasoning

The project has determined the level of scientific reasoning for each student at the pre-test (Marušić & Sliško, 2012a). These results are shown in Table 3. It can be seen that there were substantial gains towards formal operations shown by both the RPQ and ED groups.

It is interesting to observe the change in students' personal perceptions of the relationship between learning physics and development of logical and creative thinking regarding their level of scientific thinking at the beginning of the project (Table 4 and Table 5). Although the results of the pre-test by groups of thinkers for the RPQ group and the ED group are statistically significantly different it is important to observe the shift (Post - Pre) in the positive attitudes towards the two exploratory questions.

Table 3. *Percentages of RPQ and ED students in concrete-operational, transitional, and formal-operational thinking categories as indicated by pre-test scores on the LCTSR*

Pre (%)	Concrete-Operational	Transitional	Formal-Operational
RPQ group	26.4	57.1	16.5
ED group	27.1	52.9	20.0

Results for the RPQ group are shown in Table 4. Positive attitude in the first exploratory question (learning physics and the development of logical thinking) at the pre-test was shown by 41.7% of concrete thinkers, 75.0% of transitional and 80.0% formal thinkers. In this exploratory question all three groups of thinkers achieved a statistically significant positive shift at the post-test: concrete thinkers 4.1%, transitional 13.5% and formal thinkers 13.3%.

Table 4. *Changes in the percentage of students with positive attitude towards the two exploratory questions (Post-Pre) for the RPQ group in relation to the initial level of students' scientific reasoning*

		RPQ group (%)		
Exploratory questions		**Concrete-Operational (Pre)**	**Transitional (Pre)**	**Formal-Operational (Pre)**
1. I feel good when I study physics because it helps me in developing logical thinking.	Pre	41.7	75.0	80.0
	Post	45.8	88.5	93.3
	Shift	**4.1**	**13.5**	**13.3**
2. I feel good when I study physics because it helps me in developing creative thinking.	Pre	16.7	27.0	40.0
	Post	12.5	55.8	73.3
	Shift	**-4.2**	**28.8**	**33.3**

* Large Shifts in Bold - p value <0.05

In the second exploratory question, regarding teaching physics and development of creative thinking, the results are significantly different. At the pre-test the positive attitude was shown by 16.7% of concrete, 27.0% of transitional and 40.0% of formal thinkers. At the post-test the largest positive shift was achieved by formal thinkers (33.3%) which gives a total of 73.3% of them adopting a positive attitude. Transition thinkers also generate a positive shift of a statistically significant 28.8%, which gives a total of 55.8% of them having a positive attitude at the post-test. Surprisingly, concrete thinkers of the RPQ group show a drop in positive attitudes at the post-test in relation to the pre-test. This negative shift is -4.2%, which leaves the final percentage of their positive attitude towards the second exploratory question at 12.5%.

Table 5 shows the results achieved by the ED group. In the first exploratory question, related to learning physics and development of logical thinking, 47.8% of concrete thinkers, 64.4% of transitional thinkers, and 76.5% of formal thinkers adopted the positive attitude. The results achieved at the post-test show that all three groups of thinkers achieved statistically significant positive shifts (significantly larger than the shift in the RPQ group). The largest positive shift of 47.6% was made by the concrete thinkers, while the shift of 26.7% was achieved by the transitional thinkers. The shift of 23.5% made by formal thinkers at the post-test gives a total of 100% of formal thinkers with the positive attitude towards this exploratory question.

Table 5. *Changes in the percentage of students with positive attitude towards the two exploratory questions (Post-Pre) for the ED group in relation to the initial level of students' scientific reasoning*

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Exploratory questions		ED group (%) Concrete-Operational (Pre)	Transitional (Pre)	Formal-Operational (Pre)
1. I feel good when I study physics because it helps me in developing logical thinking.	Pre	47.8	64.4	76.5
	Post	95.7	91.1	100
	Shift	**47.9**	**26.7**	**23.5**
2. I feel good when I study physics because it helps me in developing creative thinking.	Pre	13.0	42.2	52.9
	Post	60.6	73.3	88.2
	Shift	**47.6**	**31.1**	**35.3**

* Large Shifts in Bold - p value <0.05

For the second exploratory question, which addresses the issue of learning physics and development of creative thinking, the results achieved by thinkers in the ED group were significantly different from those in the RPQ group. At the pre-test, positive attitude towards this exploratory question was shown by 13.0% of concrete thinkers, 42.2% of transitional and 52.9% of formal thinkers. It is important to emphasize that at the post-test all groups of thinkers of the ED group achieved a statistically significant positive shift. The largest positive shift of 47.6% was made by concrete thinkers, which gives a total of 60.6% concrete thinkers with the positive attitude. Transitional thinkers also achieved a significantly positive shift of 31.1%. At the post-test there were 88.2% of formal thinkers who adopted the positive attitude, which means a positive shift of 35.3%.

Conclusion

This study researches what the high-school graduates believe about the relationship between physics learning and developing logical and creative thinking. The pre-test results show that slightly more than 60% of the students are positive about the impact of teaching physics to the development of logical thinking. On the other hand, only about 30% of the students consider physics learning as an activity good for the development of creative thinking. These results have their roots in the very organization of physics teaching. Teaching physics in Croatian primary schools, secondary schools and universities are often characterized by the traditional form of teaching, ready-made recipes for problem solving, algorithmic assignments and tests, which might give some impressions of the necessity of logical thinking skills for physics learning but hardly shows how creativity is necessary part of doing of physics.

If students have been extensively exposed to the traditional methods of physics teaching (in course of primary and secondary education) it is difficult to change their attitudes in course of one or two semesters of university education. It is therefore necessary to act as early as possible in order to improve students' attitudes about physics and learning physics.

This research aimed at finding an experimentally proven potential way for changing students' attitudes regarding the impact of teaching physics on developing their logical and creative thinking. We were particularly focused on students' personal recognition of the development of creative thinking resulting from physics learning, whatever their definitions of these mental skills are. As said before, the study was not designed to measure the shift in creative thinking but its aim was to determine only a change of attitudes towards a relationship between learning physics and the development of logical and creative thinking.

Inspired by this problem, we explored how two different "learning packages": RPQ (*Reading, Presenting, and Questioning* modern physics topics) and ED (*Experimenting and Discussing* of "classical physical" issues, such as prediction, monitoring and explanation of simple experiments) affect students' perceptions of the relationship between physics learning and development of their thinking in domains of logic and creativity. The results show that in one semester both RPQ and ED method managed to improve students' attitudes towards the impact of teaching physics on developing their logical and creative thinking. It is particularly important to note that both methods provide a significant improvement in students' attitudes towards creative thinking in both genders.

However, regarding to the students' level of scientific thinking, ED method provides significantly better results than the RPQ method. Concrete-operational thinkers in the ED group made the biggest progress of all thinkers in this group and achieved the largest shift in the perception of the impact physics classes at school on their thinking skills. In the overall progress of the whole ED group, the contribution of concrete-operational thinkers (although lesser than the contribution of the transitional thinkers) is significantly bigger that the overall contribution of formal thinkers. That is not the case for RPQ method where only the concrete-operational thinkers do not make any progress. Indeed, regarding their attitudes towards the development of creative thinking, concrete-operational thinkers achieved a decrease in positive attitudes.

Showing such results, the ED method (with the old physics topics) proves to be a good method for improving students' beliefs regarding the impact of physics learning on developing their logical and creative thinking, and this is true for all groups of thinkers. Modern physics topics, even when they are taught in the new format, such as in the case of the RPQ group, are less effective in improving these attitudes.

The issues of content presented to the two groups could be further discussed. The question arises of whether the same results would be obtained if the topics had been the same for both groups. Namely, the ED group focused on more traditional content that students are surely more familiar with and have ready-to-use mental models and concepts that, even when being incomplete and inadequate, make possible an initial thinking and productive learning. The topics related to actual scientific experiments carried out at the CERN, presented and processed by the RPQ group, may sound more challenging and therefore more difficult to deal with, at least to the students on concrete-operational level. On the other hand, one can also argue that the contemporariness of the topic should present a further motivation to young teenage minds in search of novelty and new discoveries.

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