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The Role of Creative Thinking in Science Education

Jindriska Svobodova, Jan Novotny

***Abstract*—**A teacher's attitude to creativity plays an essential role in the thinking development of his/her students. The purpose of this study is to understand if a science teacher's personal creativity can modify his/her ability to produce various kinds of questions. This research used an education activity based on cosmic sketches and pictures by K.E. Tsiolkovsky, the founder of astronautics, to explore if any relationship between individual creativity and the asking questions skill exists. As a screening instrument, which allows an assessment of the respondent's creative potential, a common test of creative thinking was used. The results of the creativity test and the diversity of the questions are mentioned.

***Keywords*—**Science education, active learning, physics teaching, creativity.

I. Introduction

TEACHER-STUDENT questioning strategies are essential elements in teaching. Questioning represents an interactive relationship between teacher and student. Teaching and learning through questions is more challenging than only presenting facts. Various studies have shown that using questions only at the low cognitive level cannot provide more active and creative learning. Cognitive processes include associative thinking, analytical thinking, encoding, and are potentiality associated with more fundamental cognitive abilities, for example with associative memory, meaningful memory, ideational fluency, expressional fluency, figural flexibility, etc. These cognitive abilities can then be targeted by specific pedagogical strategies. The understanding of the creative process stops being only procedural (steps to solve a problem) and becomes deeper, at a cognitive level [1]. Moreover, the debates are a great way for students to get involved in class. Students have to research several physical topics and prepare for the debate.

Science begins by asking questions and then seeking answers. The scientist's creativity and rational insight are confronted with observations to develop a model of a researched situation.

Every scientific model, as a simplified and idealized system, mediates between theory and reality and consequently gives an opportunity to formulate many questions. The study needed to evoke the situation of provoking different questions in the context of the common science educational process. Undergraduate physics students were introduced to an activity inspired by sketches, pictures and notes by K.E. Tsiolkovsky, the founder of astronautics.

Konstantin Eduardovitch Tsiolkovsky was the Russian visionary and mathematics teacher, who in 1897 deduced this equation. In his book published in 1903, "Cosmic Space Exploration with Reaction Engines", he discussed for the first time propulsion based on a mixture of liquid hydrogen and oxygen, multistage rockets, space suits and attitude control through the use of gyroscopes, among many other daring and revolutionary ideas. His statement: "Our planet is the cradle of intelligence, but one cannot live forever in a cradle" summarizes the belief shared by many that space exploration is an inevitable implication of human development. Inspired by Tsiolkovsky, scientists, engineers, and science fiction authors have come up with exciting ideas for new methods of sailing in space using solar radiation, navigation impulse and extraterrestrial life. Tsiolkovsky's lifework is powerful tool for exploring the human mind and its potential creativity. He produced hundreds of works of cosmic philosophy; and tried to summarize his thoughts as sixteen theorems of life. His ideas about the "Origin of life" are similar to the present-day views of ordinary people. He was convinced that we all need to look at our life on Earth from the height of space. [6]

Tsiolkovsky's ideas were introduced to the students to engage in technical, physical and cultural discussion. Thinking about the duration of and our standing in the cosmos is a central concern of every civilization.

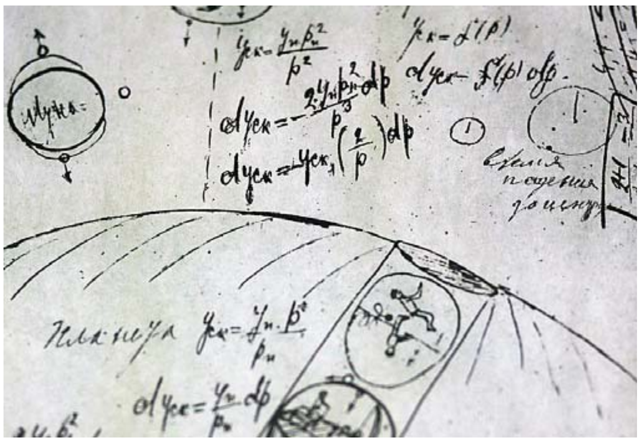

Fig.1 Handwritten math remarks and drawings from Tsiolkovsky's, "Cosmic Space Exploration with Reaction Engines" [6]

II. Methodology

The relationship between personal creativity and producing various levels of questions was monitored. The respondents consisted of 24 students at Masaryk University preparing to become professional science teachers. The students were led to ask spontaneous questions about selected images and science sketches. The sketches helped to explore a science concept and understand an idea. The drawings come from the free online archive of the Russian Academy of Sciences,

Jan Novotny is with the Masaryk University, Department of Education, Czech Republic (e-mail: nnovotnyy@gmail.com).

which is the keeper of the personal archive of Tsiolkovsky's. [2]

The students - future teachers, learn to teach through their participation in interactive activities, such as "How do Astronauts Live in Space" and "The Flight of your Rocket" and they improve their knowledge by gathering information from scientist's notes and drawings [2], [6]. The students were asked to devise adequate questions about space travel, and then formulate the desired answers, too. The questions can be concerned with rocket travel, designs, space station equipment, airlocks for exiting, rescue systems and closed-cycle systems to provide food and oxygen for space colonies.

The Tziolkovsky sketch, "Visual and force conditions in a rocket" was submitted to the students for conversation and questions producing.

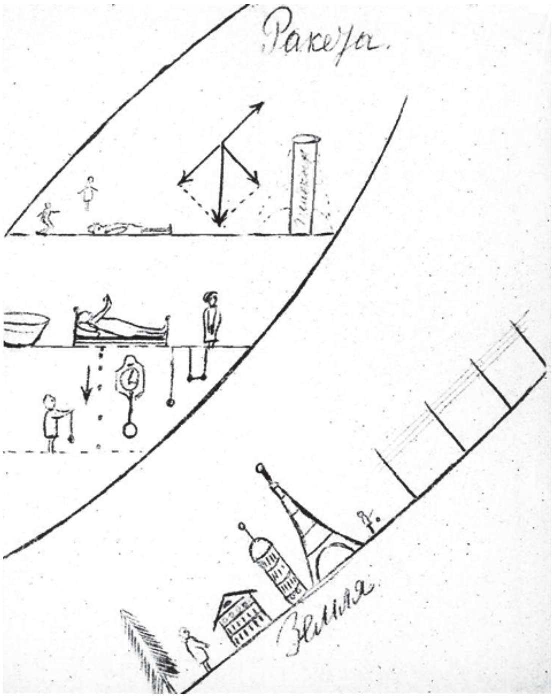

Fig. 2 The sketch of K. Tziolkovsky [2]

Each student (future teacher) was then expected to compile and develop several questions about the pictured problem statement. His questions were formulated to target imaginary learners. He had to concern how the simulated problem began, how it may impact the future. The purpose was to create good teacher's questions to lead step by step debate on possible science solutions.

We recorded their created questions and student's ideas of adequate learers responses, too. For the purpose of the research study, the quality of the questions (and expected answers) generated by the students needed to be assessed in the context of science teaching. Selections of the different types of questions are listed below.

- Closed question: Does the altitude of the rocket above the surface change?
- Open question: How would you explain that the depicted ground surface is slanted?
- Low cognitive question: What forces act on the rocket?
- High cognitive question: Can you give reasons why you think that rocket accelerates?

Subsequently, the same students were invited to test their current creative potential using a test based on the idea of creativity as a result of divergent thinking, the standard Torrance figural test of creative thinking (TTCT), which wasx first published in 1966. It includes a verbal and a figural part. The results reveal these scored characteristics: fluency, flexibility, originality, elaboration and abstraction. Reliability of the test according to dozens of studies is more than 0.9 [3]. The TTCT advantage is its independence on cultural backgrounds. For the purpose of this study, it was sufficient to distinguish the creativity score quotient for respondents as low level, middle level, high and higher level.

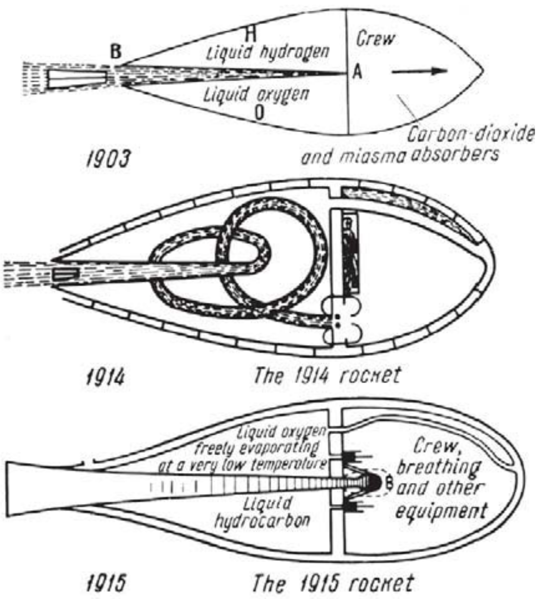

Fig. 3 The design and relationship between the final velocity of the rocket and the ejection velocity of the propellant was given by the Tsiolkovsky [2]

Data items (questions generated by students) were organized according to their main characteristics: Low/High cognitive questions and Closed/Open questions. Low cognitive questions are those which ask the student to recall in his own words material previously read or taught. Higher cognitive questions are those which ask the student to manipulate the knowledge previously learned to create an answer and to support it with logically reasoned evidence. From another point of view, closed and open questions can be distinguished. A closed question requires an unambiguous response, which is contrary to an open question, which does not intend to be reduced to possible answers. The advantage of open questions is that they stimulate creative and critical thinking. A teacher can analyze the content of a pupil's response in more detail and can more easily assess is his/her understanding. Formulating open questions is more difficult for teachers than designing closed questions. [4], [5].

III. Measurement of Personal Creativity

The creativity test TTCT was given to 24 students.

The verbal part of test consists of tasks: ask-and-guess, product improvement, unusual uses, unconventionality, etc. For example, participants are shown a picture and asked to respond in writing. They might be shown a situation and asked to improve products.

The figural part consists of picture construction, picture completion, and repeated figures of lines or circles. In the picture completion task participants are given several incomplete pictures and are asked to construct a new image. The test is designed to evaluate four main direct measures:

- Fluency - the total number of interpretable, meaningful, and relevant ideas generated in response to the stimulus.
- Flexibility - the number of different categories of relevant responses.
- Originality - the statistical rarity of the responses.
- Elaboration - the amount of detail in the responses.

In addition, other referenced measures were taken into account, which include: emotional expressiveness, actions, syntheses, unusual visualization, extending boundaries, humor, richness of imagery, and fantasy. Sum of all rating points achieved for particular measures was taken as creativity degree estimation.

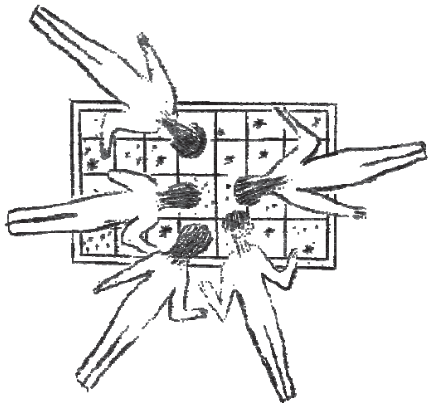

Fig. 4 A drawing from Tsiolkovsky's 1933 manuscript portrays floating people looking at stars through a window [2]

IV. Measurement of Personal Skill Asking Questions

All the science questions produced by students working with Tziolkovsky's documents were categorized according to the level of complexity. The separated questions paired with the criteria: Low/High Cognitive question, Closed/Open question.

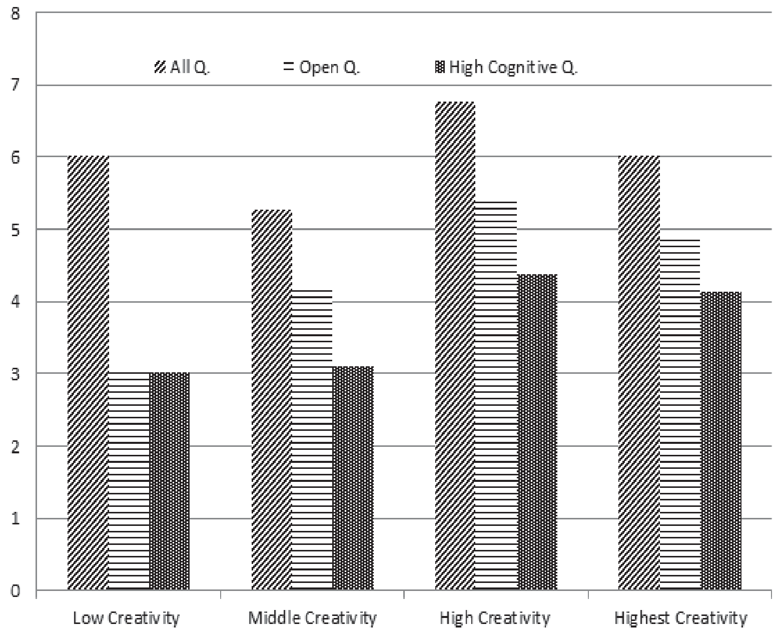

Fig. 5 The horizontal axis shows the estimated personal level of creativity and the vertical axis shows the average number of questions per student

A combination of qualitative and quantitative approaches was used. Qualitative data gathered from the study were converted to numbered quantitative data and were discussed comparatively. After converting the collected data into quantitative form, common descriptive statistic methods were applied. Statistical analysis of the responses was performed using Excel; the specific tests were Spearman correlation. The responses from 24 participants were categorized and coded.

The preliminary experiences hinted that a relationship between personal creativity and skill for question asking exists. The main research question was formalated as follows:

What is the impact of students' creativity on their question asking skill?

Three hypotheses were formulated and then translated to testable statements:

H1. There is a significan, positive relationship between the creativity level and number of produced questions.

H2. Students with a high degree of creativity produce more open questions.

H3. Students with a high degree of creativity produce more thought-provoking (higher cognitive) questions.

V. Results

The correlation between the factors expressed in the statements of the author's hypotheses was checked. Spearman's rho non-parametric test was used to measure the strength of the association between the variables. For the data, where $n = 24$ and $\alpha = 0.05$, a critical Spearman's rho value of 0.407 was obtained. If the calculated Spearman's rho is greater than the critical value, there is no verifiable correlation. The calculations allow for the following decisions:

H1. There is a significant positive relationship between creativity level and the number of produced questions, $0.407 > 0.361$, the researchers reject the H1 statement.

H2. Students with a higher degree of creativity produce more open questions, $0.407 < 0.784$, the researchers accept the H2 statement.

Students with a higher degree of creativity produce more thought-provoking (higher cognitive) questions, $0.407 < 0.534$, the researchers accept the H3 statement.

VI. Discussion

Research shows that all respondents could generate a relatively large number of questions. The results support the decision that there is no relationship between personal creativity level of the respondents and the total number of questions they can produce. Every student was able to formulate four to five questions about one Tziolkovsky sketch. More than 30% of participants generated closed questions.

Inspired by the Tziolkovsky drawings, almost 90 different questions were generated and categorised according to the type of question - Open/Closed and Low/High cognitive.

Analysis of the data showed that respondents with higher creativity were able to formulate more open and more high-cognitive questions.

The relationship between the proficiency to ask high cognitive questions and creativity was only slightly proven. A larger statistical sample of respondents would be required to increase the reliability of the test.

VII. Conclusion

The researchers have tried to stimulate and challenge the students–future physics teachers–to think deeply through existing science concepts and proven models. If students–future teachers-have an opportunity to get feedback if their formulations of questions are appropriate for certain scientific context and for particular teaching situation, they can make a good progress. Particular context is decisive in determining whether open and closed questions are scientifically productive. The works by Tziolkovsky include many humanitarian aspects of technical achievements in outer space. In preparing students for a future professional teaching career, the researchers have attempted to provoke their ability to find broader contexts and to an appreciation of the human spirit.

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