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A conceptual model of the role of the instructor in fostering students' mathematical creativity

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ABSTRACT

Several studies tried to introduce some of the efficient factors that can influence fostering mathematical creativity in learning environments. since some of the variables associated with mathematical creativity in educational environments depend on the culture, conducting research in this area seems necessary. It should be noted that the contribution of Iranian researchers to these studies is very small. The paper aims to study the role of instructors in nurturing creativity in mathematics students from math students' point of view and to present a conceptual model. The research is a qualitative study conducted using grounded theory. Participants were selected from university students who are studying mathematics in the universities of the city of Tehran in Iran using purposive sampling and the sampling is stopped until theoretical saturation. Finally, semi-structured in-depth interviews were conducted with 10 students. Interviews were audiotaped, transcribed, and coded in the two stages of free coding and axial coding. Classification of codes led to numerous categories. The findings show that instructors can influence several aspects: belief, intention, mathematical knowledge, mathematical thinking, and personality characteristics such that being persistent, being a risk taker, and forgetting fixation.

INTRODUCTION

Developing creative thinking is important in educational settings (Zubaidah et al., 2017). Mathematics, because of its nature and construct, can provide a suitable setting for strengthening skills such as generalizing, modeling, making conjectures, and solving problems which seem to be the necessities of creativity and its advancement (Kozlowski et al., 2019; Daher & Anabousy, 2018; Sriraman & Haavold, 2017). Creativity in mathematics, which is called mathematical creativity, is often considered a mysterious phenomenon. Most mathematicians seem to be not interested in analyzing their thinking processes (Ervynck; 1991) and do not describe how they work or develop theories.

Researchers have attempted to define the concept of mathematical creativity, but there is no universally accepted definition (Kozlowskiet al., 2019; Daher & Anabousy, 2018; Arikan, 2017; Sriraman & Lee, 2011; Sriraman, 2005; Mann, 2005; Haylock, 1987). Some researchers (Hadamard, 1945; Poincare, 1948, 1956; Ervynck; 1991) assert that discovery in mathematics or any other area is a result of combining ideas and considering the combination of old ideas in a new way as a creative activity. Ervynck (1991) believes that the creation of useful mathematical concepts by combining the concepts previously known or discovering unknown relationships between mathematical facts or ideas can be considered creative work. Chamberlain and Moon (2005) also regard divergent thinking as an accepted description of mathematical creativity. Laycock (1970) regards mathematical creativity as an ability to analyze a given problem in different ways and to choose an appropriate

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method to deal with unfamiliar situations in mathematics. Sriraman (2005) believes that mathematical creativity is not just the realm of the mathematician who discovers something for the first time, but also the realm of someone who discovers something previously known. Mathematical creativity is not an issue only related to the particular field of professional mathematicians and can also be raised at the level of students. Several researchers (Kozlowski et al., 2019; Arikan, 2017; Grégoire, 2016; Sriraman et al.,2013; Wessels, 2014; Prusak, 2015; Sharma, 2014; Jaleel & Titus, 2015; Hamid & Kamarudin, 2021; Bicer, 2021) suggest that nurturing creativity in mathematics should be considered an essential component of mathematics education.

Some researchers distinguish between mathematical creativity on professional and educational levels (Grégoire, 2016; Liljedahl & Sriraman, 2006; Shriki, 2010). Mina (2008) also believes that the newness and novelty of products of creative processes in mathematics are sufficient for students. Many researchers believe that on the educational levels, mathematical creativity is generally associated with activities such as solving non-routine problems, solving problems creatively, solving multiple solution tasks, solving open-ended problems, problem posing, generalization, and making connections between seemingly unrelated ideas (Silver, 1997; Sriraman, 2009; Liljedahl &Sriraman, 2006; Chamberlin& Moon, 2005; Ellwood et al., 2009; Haylock,1987; Kim, 2009; Yuan & Sriraman, 2011; Kontorovich et al., 2011; Leikin & Lev, 2013; Sriraman et al.,2013; Leung, 1997; Wessels, 2014; Bicer, 2021). Some studies also consider solving mathematical Modelling problems as creative activities at educational levels (Wessels, 2014, Weinhandl & Lavicza, 2021; Hamid & Kamarudin, 2021; Bicer, 2021; Lewis & Colonnese, 2021; Bonyah & Clark, 2022). According to Bonyah and Clark (2022), mathematical modeling can improve problem solving skills and can lead to creativity. It is necessary to include tasks, and mathematical modeling activities appropriate in the curriculum of different educational levels (Bonyah & Clark, 2022).

In their study on the understanding of culturally-based aspects of mathematical creativity associated with educational environments across six participating countries, Leikin et al. (2013) address teachers' conceptions about who is a creative student in mathematics. Their results show that "*teachers consider students to be creative if they have investigative abilities, are mathematically flexible, and succeed in problem solving*" (p. 322).

Some studies tried to identify some of the effective factors that can develop mathematical creativity at the educational levels (Kozlowski et al., 2019; Grégoire, 2016). For instance, the effective factors at the individual level that could be mentioned are an individual's internal beliefs, intentions, mathematical knowledge and skills, and personality characteristics.

Researchers believe that the content knowledge of a person can enhance his/her creative solutions to mathematics problems. In their study, Yuan and Sriraman (2011) concluded that mathematics knowledge is an important factor in individuals' ability to problem posing and there is a significant relationship between these two. However, content knowledge alone is not enough to solve challenging problems and awareness of how and why these relationships among components of the knowledge are also necessary. In solving a problem, the person may need to synthesize his/her content knowledge in a new way. In other words, if the person has content knowledge that is organized very well in his/her mind, his/her ability in using appropriately this knowledge and strategies can be enhanced. If the knowledge is not well organized or integrated into the mind, it cannot be used in a given setting. This indicates the importance of understanding and insight. Ervynck (1991) believes that understanding and insight are considered moving power of mathematical creativity.

Kattou et al. (2012) tried to identify factors that assess creative ability in mathematics. They realized that for assessing an individual's creativity in mathematics, mathematical knowledge, and also abilities including spatial, inductive, and deductive reasoning can be used. Like many researchers (Kozlowski et al., 2019; Daher & Anabousy, 2018; Ervynck, 1991; Hadamard, 1945 and Poincare, 1948, 1956), they believed that creativity in mathematics is the ability to see new relationships and to link seemingly unrelated ideas. Since the person needs to synthesize mathematical ideas, in creative activities, mathematical knowledge and abilities are important and influential factors in mathematical creativity. The standard of connection as one of the standards of the National Council of Teachers of Mathematics (2000) for school mathematics emphasizes making connections among concepts and processes.

Various researchers emphasize that the beliefs and intentions of mathematics students influence their creative solutions to mathematics problems (Kozlowski et al., 2019; Grégoire, 2016). Schoenfeld (1992, 1985), Sternberg (1996), Johnson (1997), Burton (1999), Brunkalla (2009), and Mann (2009) focus on the importance of intentions and beliefs in solving non-routine problems. Schoenfeld (1992) asserts that most students believe that there is only one true solution for each mathematical problem. Probably this belief is shaped under the influence of the beliefs of their teachers. The teacher's beliefs about mathematics and its nature have a great influence on choosing teaching methods and also on the students' beliefs (Hersh, 1998). For example, if a teacher believes that mathematical topics are not separate islands, then he/she will be able to perform the activities in the classroom in such a way as to make the audience realize the connections.

Based on numerous research results, teachers and lecturers and their personalities are among the factors influencing the development of mathematical creativity in classrooms (Smedsrud et al., 2022; Cai & Leikin, 2020; Bicer, 2021; Fetterly, 2020; Anderson et al., 2022; Rupnow, 2021; Andrade & Pasia, 2020). For example, instructors' beliefs (Andrade & Pasia, 2020; Fetterly, 2020) and their mathematical knowledge level (Andrade & Pasia, 2020; Bicer, 2021; Smedsrud et al., 2022) can be effective in developing mathematical creativity in students. Instructors can guide students to creative thinking by asking questions that encourage flexible thinking. Creative teachers allow students to take risks, make mistakes, and find multiple solutions to problems. students (Andrade & Pasia, 2020).

A lot of research has been done in various countries in school and university environments. However, surveys show that there are still many aspects of mathematical creativity in educational environments that are unknown to experts. In particular, little research has been done at the tertiary level (Regier & Savic, 2020; Rupnow, 2021). The research on the nature of mathematical creativity also indicates that its development is strongly dependent on learning environments (Kaufman and Sternberg, 2006). Also, since some of the variables associated with mathematical creativity in educational environments depend on the culture (Leikin et al., 2013), conducting research in this area seems necessary, especially a kind of research in which this phenomenon is studied about some other factors, including the cultural context in which the experiences, attitudes, intentions and mathematical beliefs of people have been developed. It should be noted that the contribution of Iranian researchers to these studies has been indirect and very small.

Thus, for making constructive changes in the mathematics education system and providing a dynamic environment that fosters mathematical creativity, it is necessary for the education system not to be consumers of others' theories, but to conduct research that leads to formulating fundamental theories in different areas within society through considering society's contextual features. In other words, researchers should be able to introduce theories that originate from their society. One of the necessary steps in this regard is conducting qualitative research through an exploratory approach to obtain a more accurate and complete view of the realities. As we know, in learning environments, teachers and instructors are influential factors in the improvement of mathematical creativity, not only at the school but also at the university. This study is an attempt to study some aspects of this phenomenon in the Iranian society with a qualitative approach, and that answers the question that how an instructor can influence fostering mathematical creativity in learning environments from mathematics students' point of view.

METHODS

The purpose of this study is to examine the role of the instructor in fostering mathematical creativity in learning environments from mathematics students' points of view and present a conceptual model. Since this phenomenon is examined for the first time, at least in Iran, an appropriate research method is needed to analyze this phenomenon carefully. A qualitative approach such as grounded theory is appropriate. The participants include all students studying mathematics in some of the universities in Iran. 10 students, who could provide thorough information to the researcher for discovering a conceptual model, were selected for introspective semi-structured interviews. The sampling was stopped when categories were theoretically saturated.

Creswell (1998) considers the interview as one of the most important tools for collecting data in grounded theory. The instrument for data collection in the present study is introspective semi-structured interviews. Before interviewing each student, a brief explanation of the purpose of the research was given to them. With their permission, the interviews were recorded.

After each interview, the content of the interview was transcribed and presented to the interviewees for confirmation. After making sure of the accuracy of the transcriptions, the content was coded for further analysis. By examining it line by line, key points were extracted for conceptualization and categorization. Then open and axial coding was done. After that, the next interview was done, and the above-mentioned stages were repeated. Since the purpose of this research is to develop a conceptual framework, the third step of coding, i.e., selective coding is not needed (Strauss and Corbin, 1998). In this study, MAXQDA software is used for data analysis.

To establish the quality of the study, the standards proposed by Guba and Lincoln (1985) are used: credibility, dependability, transferability, and conformability standards are set forth under the title of trustworthiness standards in qualitative research. They are used to see how much the research findings can be trusted. The researchers have taken steps to establish the validity of the present study:

1. During the research process, always the researchers have maintained their continued and long interaction with the participants, data and the research field and tried to increase this interaction.
2. The researchers have shown their data and findings to the participants to make sure of the accuracy of their inference and have used their modifications of participants.
3. During her interviews with the participants, the researchers repeated the interviewees' statements in their own words, sometimes, so that their understanding and interpretation be confirmed (Re-voicing and Paraphrasing techniques).
4. After each interview and its transcription, the researchers, in addition to coding the interviews themself, have benefited from other experts' help encoding the interviews and sometimes have done the coding process, cooperatively with those experts.
5. The researchers have shown their data to the experts and have asked them about their data analysis and the accuracy of the data.
6. Qualitative researchers utilize different memos (Guba & Lincoln, 1985). In this study, during the research process, the researchers always recorded and wrote down their research procedures and have used their personal and analytical notes.
7. The researchers have documented their data objectively.
8. Always the researchers have tried to be accurate enough in interviews, data analysis, and also in presenting a conceptual model and following the experts' advice.
9. The researchers selected participants who had more interaction with the subject under study and could provide thorough information.

FINDINGS

The In this section, qualitative data analysis is presented. Qualitative data collected from the process of conducting in-depth semi-structured interviews with research participants were analyzed using open coding and axial coding. The implementation of the open coding process on the collected qualitative data first led to the extraction of a large number of concepts, which were reduced and categorized based on the similarities and commonalities of the concepts. The findings of the coding process show that based on the views of the participants of this research, the role of instructors in fostering students' creativity has been dependent on some factors or categories. The conceptual model extracted from the coding process is shown in Figure 1.

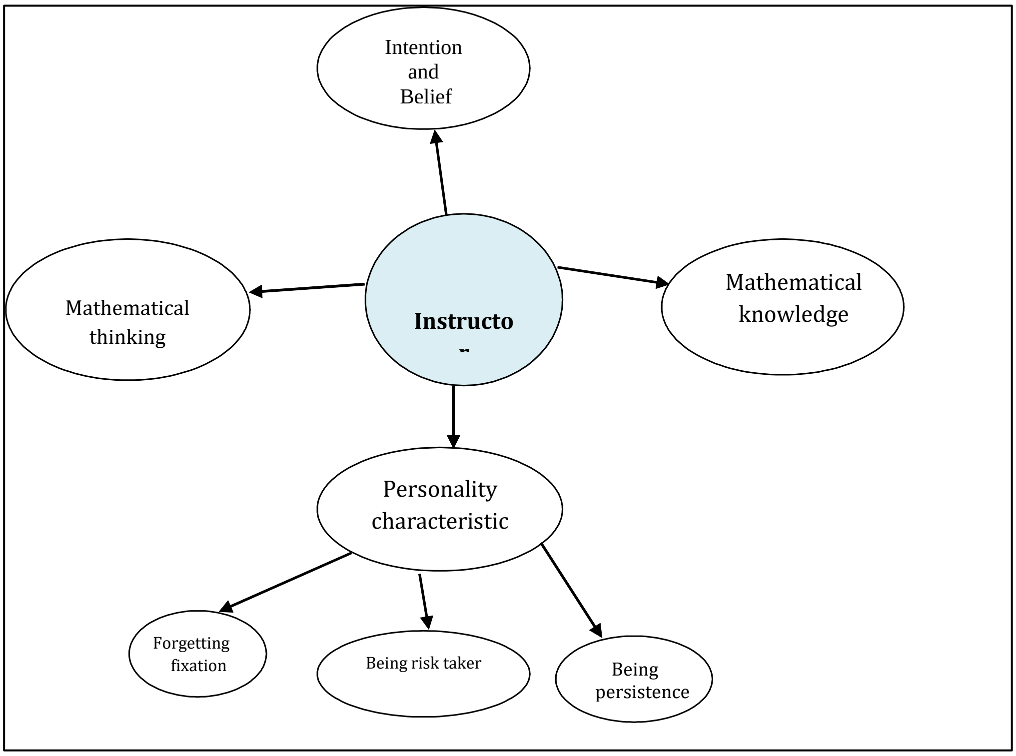

Figure 1. The conceptual model of the role of the instructor in fostering students' mathematical creativity

Participants mentioned the instructor as the most influential factor in mathematical creativity. The results reveal that there are several subcategories. The instructor can influence several aspects: belief, intention, mathematical knowledge, mathematical thinking, and personality characteristics such that being persistent, being a risk-taker, and forgetting fixation.

According to the results of the coding process, all participants agreed that the role of the instructor is very important:

"*I am very dependent on my instructors. If my instructor is a good one, I perform better… I need someone to push me to solve the problem. I will not study unless I am forced*."

"*A good instructor is very important. If a person spends half of his life searching for good instructors, he has lost nothing. The instructor guides you to be creative. Since the instructor is experienced and has experienced errors, he knows how the process works. All great people of course had great instructors*".

Participants believe that students should be permitted to declare their views and reasoning. They mention giving the learning opportunity to the learner to be active. This can itself be influential in fostering students' creativity. In other words, they look at opportunity and time for learning from two points of view; one is the sufficient time and opportunity for mastering mathematics topics and concepts and the other is the time and opportunity for thinking about the problems. Students should be taken sufficient opportunities to engage in struggling to solve challenging mathematics problems and tasks which could lead them to experience mathematical creative activities like mathematicians, who have been able to create new mathematical insights and ideas. Below are some examples of participants' ideas:

"It is better than the instructor poses a problem while he is speaking and giving the students time to think on it and everybody express their ideas, regardless of being true or false. I almost do it myself. One of the instructors said: express your ideas, even if they are wrong. In this case, the student tries to find his errors to become able to solve the problem."

"The instructors teach a huge number of topics very fast. We do not have enough time to reach mastery and find a method to prove the theorem by ourselves. When four similar theorems and their proofs are presented to me, I would like to find a way to prove the fifth one by myself. The instructor doesn't give this opportunity to us in class. It would be good if the instructor introduced a theorem and asked us to think about it together."

"It is hard to be creative in mathematics; because students are taught in a way that prevents creativity. For example, when we enter university, instructors prove some theorems for us. We are not free to express our ideas. If we want to do this, we should spend time."

"Perhaps, the creativity is neglected and remains unused. But an instructor may say something or pose a mathematical problem which flashes an idea in the mind."

"A good instructor is influential. But he cannot make the person creative. However, he can develop the creativity of his students by providing an appropriate opportunity and context. For example, when the instructor lets the students speak in the class and express their ideas and does not suppress their creativity, he has provided the opportunity for the student's creativity to flourish."

"The instructor or the teacher should avoid ignoring the individuals who have solved the problem. If the person has not had a strong will and determination, he will put aside creative solutions when he sees his creative idea is not considered important by instructors."

Participants further mentioned that instructors should be responsible for implementing mathematical creative activities, for instance, problem posing is one of these activities or giving problems that help individuals to overcome fixation.

"The guys do not welcome problem posing, because they are used to teachers posing problems and guys think about the solutions. No instructor has ever asked us to pose a challenging question or problem in math."

"I would like my instructor presents an attractive problem in the class and want to spend time solving the problem. An attractive problem seems easy, but when you want to solve it, you find out it is not that easy. You spend one day, 2 days, or 3 days, working on the problem but it remains unsolved. You need to have more perseverance. It is somehow like interesting combat. You should insist on solving it. In courses in "Number Theory" and "discrete mathematics", such events happen frequently."

Participants' declarations in this study show that instructors have a great influence on improving mathematical knowledge. Participants believe that mathematical knowledge is influential in presenting creative solutions. It can also be influential in strengthening his/her positive beliefs.

"Instructors can influence on improving our mathematical knowledge. If I learn mathematics very well, it is influential in presenting a creative solution. I should know and learn mathematics so that I recognize which method to use, or which other problem can help solve a given problem. These are all important. Also, if our mathematical knowledge increases, our interest may increase."

The instructor has a great influence on the intentions and beliefs of mathematics students and can also strengthen their perseverance which is one of their personality characteristics. Particularly, instructors can motivate individuals to do mathematical creative activities.

"Instructors can encourage me that try to solve challenging problems, and this is because of my interest in solving a problem. The interested one would not be limited to studying a few resources and trying to study more. That means that he does not narrow his knowledge and is motivated to extend it. If one is not interested enough when confronted with difficulty in solving a problem, one may give it up and say: I cannot solve it."

"The instructor should motivate students to solve the problem and encourage them and pay attention to this activity. For instance, after teaching, it is better that the instructor gives some

problems to the students and ask them to think about them in class and solve them. Then the dialogues and activities start: One says, "Where should we start from?" One says, "If we consider x". The other says…". Solving a problem in group work is easier and better … of course, the person himself should also want to work in class [intentions] and should not just listen to the dialogues. In doing so, it can make students interested in mathematics."

"If a person has talent in mathematics, then a good teacher can have a revolutionary influence on him and can change him. I wasn't interested in mathematics and hated it until I started the 9th grade in high school. However, my 9th grade teacher made a revolution in me and had a great influence on me and made me interested in mathematics, so I decided to study mathematics. My teacher's behavior was a great inspiration for us. His interest in the job was admirable. His teaching method was creative. His class atmosphere was very exciting, and the students were united. He taught the topics in the easiest form through mathematics games. Learning mathematics through the game is very good. Games are what we have grown up with, from childhood. I wish all instructors would be like him."

Thus, the instructor can create a situation that provides the context for mathematical creativity improvement.

DISCUSSION

The findings of the present study show that the role of the instructor is very important and can influence mathematical creativity from several points of view: individual's belief, intention, mathematical knowledge, mathematical thinking, and personality characteristics such that perseverance. The findings are in line with the findings of Schoenfeld (1992), Kiymaz, et. al (2011), Sinitsky (2008), Mina (2008), Bonyah and Clark (2022), Anderson et al. (2022), Fetterly (2020), Rupnow (2021), Andrade and Pasia (2020), the findings of these studies emphasize the vital role of teachers or instructors. The findings of Sinitsky (2008) indicate that teachers should be taught mathematical creativity for different grades and age groups to enhance teachers' creative experiences in mathematics. Sinitsky believes that teachers' mathematical creative experiences have an important role in introducing activities related to solving creative problems in the class. Also, the findings of Mina (2008) emphasize the role of the teacher in motivating individuals and recognizing their abilities, and also the management of the environments that foster creativity. Mina believes by recognizing abilities and individuals' characteristics of that level and appropriate approaches to each education level we can truly have an appropriate environment for fostering mathematical creativity.

Haylock (1987) also suggests that it is a vital need for mathematics teachers and instructors to know mathematical creativity at all levels and encourage and foster it. However, a question arises how much they are aware of learning environments that foster mathematical creativity? Many studies show that teachers, generally, and mathematics teachers in particular desire to teach the same way they have been taught in schools (Shriki, 2010), and Sinitsky (2008) suggests that the teachers' creative educational experiences have a vital role in convincing them to use creativity in planning and executing mathematical activities in the class for developing mathematical thinking. On the other hand, teachers and instructors often forget the importance of struggling to solve challenging problems that they faced during their schooling (Sinitsky, 2008).

CONCLUSIONS

It seems necessary to pay attention to teachers' education, especially to improve their ability to plan and implement educational activities that develop an individual's mathematical creativity ability. In such environments, looking at a problem from different perspectives is necessary for fostering creativity, not only is not rejected, but also various ideas are welcome and appreciated. Teachers should guide and direct individuals by asking questions that enable their flexible thinking so that they gain enough experience for reconstructing mathematical concepts and ideas and can reflect on mathematical ideas and relations. For doing mathematics like mathematicians and thinking like them, opportunities should be provided for individuals to learn to search, make conjectures, make hypotheses, analyze, reject, employ strategies, plan, execute, conclude, and reach a conclusion, justify, reflect, and also monitor to be able to experience the processes which mathematicians take for creating ideas. To do so, teachers and instructors should use educational approaches that appreciate individuals' potential and the ability to create various and unusual responses to problems; instead of just emphasizing rules, algorithms, and procedures without considering the essence and nature of mathematics." *The essence and nature of mathematics are not just coming up with a true answer, but it is thinking creatively*" (Ginsburg, 1996, p. 185). In this method, teachers should not only emphasize procedures and the speed and accuracy required for acquiring answers for problems but also should try to provide a safe atmosphere for individuals to go beyond known mathematics facts, so that they have opportunities for their thoughts to float for creating or recreating mathematical ideas. In this case, they can discover and understand mathematical knowledge and use it in new situations to offer intelligent and insightful answers and also think creatively and flexibly about mathematical ideas. Teachers must provide learning environments that make opportunities available for learners to share their insights and ideas with other classmates. In such learning environments, the teacher does not give the answers directly but helps individuals to be involved in solving challenging problems and to reflect on their mathematical understanding to be able to have new ideas and plans for solving problems. In such an environment, individuals are encouraged to take risks and make errors and they have the chance to experience various ways of solving problems. Preparing and implementing such learning environments leads to mathematical creativity development. Despite that, in practice, such environments are neglected and are not intended in formal institutes and university structures (Hong and Milgram, 2008).

Even teachers who recognize the importance of nurturing creativity in students often do not make the attempt for this in the classroom (Prusak, 2015). Perhaps we can say most students directly or indirectly are trained in a way that they think that mathematics is just logical, solvable and explicable. These learners are unaware of behind the scenes in math. Teachers often do not show these behind the scenes to their students. Perhaps you saw the teachers or instructors when have forgotten the theorem that they want to teach in the class, they write for themselves something on the margin of the board (in a way that the audience can't see) and erase it immediately. However, we wish those perceptions and behind the scenes and processes undergone to reach the answer were made explicit, so that the learners would not think mathematics is from the very beginning explicit and ready with formal proofs. As a result, students conclude that they can also be mathematics creative people and can play their role in recreating mathematical knowledge and at the same time become familiar with a creative thinking process of a problem solver.

Hope that educational systems and education professionals explain the teaching-learning process more accurately based on scientific findings by making good changes in the educational system and providing a dynamic environment, making the learners face challenging situations and problems, and providing the context for the advancement of creativity while struggling for solving these problems.

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