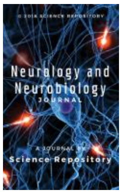

Available online at www.sciencerepository.org

Science Repository

Research Article

S.T.E.M.: Inquiry-Based Learning and Gifted Education

Kefalis Chrysovalantis[1*] and Athanasios Drigas[2]

[1]*Research Associate, N.C.S.R. "Demokritos", IIT-Net Media Lab & Mind - Brain R&D, Agia Paraskevi, Athens, Greece*
[2]*Research Director, N.C.S.R. "Demokritos", IIT-Net Media Lab & Mind- Brain R&D, Agia Paraskevi, Athens, Greece*

ARTICLE INFO

Article history:
Received: 2 October, 2020
Accepted: 15 October, 2020
Published: 23 November, 2020

Keywords:
S.T.E.M.
gifted
inquiry-based learning
metacognition
science
robotics

ABSTRACT

The aim of this paper is to investigate the relationship between the education of gifted students and S.T.E.M. activities. More specifically, we investigated whether the characteristics of inquiry-based learning (the teaching method that is mainly used in S.T.E.M. education), such as collaboration, exchange of views, complexity, etc. are compatible with the needs and learning preferences of gifted students. Then we explored applications of such activities and their results in gifted education. According to our results, the characteristics of inquiry-based learning are compatible with the preferences of gifted students, while the results of the application of S.T.E.M. activities in the education of gifted children are effective.

Introduction

S.T.E.M. stands for Science, Technology, Engineering and Mathematics. In recent years this interdisciplinary teaching method has been gaining more and more attention in the scientific community [1-4]. According to Li *et al.* the fact that the term S.T.E.M. is not very long leads to the fact that it is not very clearly defined [4]. The history of the term begins around the early 90's. The US National Science Foundation (NSF) integrated Engineering and Technology in Science and Mathematics education for k-12 education. At first the acronym used was SMET (science, mathematics, engineering and technology). Later the acronym SMET was replaced by STEM.

According to English and Li S.T.E.M. education can be seen in two ways [3, 5]. Either as a broader perspective on the teaching of the various components, such as science education, mathematics and engineering, or as interdisciplinary combinations of the individual components. Education in these areas develops students' basic skills (problem solving, critical thinking, etc.) [6-9].

Inquiry-based learning seems to be more effective in the education of science and technology within the general population. The new values of societies and educational systems, especially after the 1980s, focused on learning through Inquiry. This shift has changed the way we look at teaching and learning in general. Of course, the idea of Inquiry may not have been new, but its degree and scope of acceptance is [10-16].

In terms of gifted education, we need to identify whether inquiry-based learning and S.T.E.M. education are effective in this case as well. In other words, we have to look at what are the characteristics of Inquiry-based learning and see whether these characteristics are compatible with gifted students [17-19]. Then, we need to consider whether S.T.E.M. education is compatible with the educational needs the gifted students though the implementation in gifted education.

Inquiry Based Learning and Gifted Education

According to Trna (2014), a key factor in the development of gifted students is motivation. The behaviours of gifted pupils in the context of

*Correspondence to: *Kefalis Chrysovalantis, Research Associate, N.C.S.R. "Demokritos", IIT-Net Media Lab & Mind - Brain R&D, Agia Paraskevi, 15310, Athens, Greece; E-mail: vkefalis@iit.demokritos.gr*

http://dx.doi.org/10.31487/j.NNB.2020.04.01

education differ from the pupils as a whole and include the following behaviours [20].

- They are not satisfied with passive memorizing.
- They ask more questions.
- They are curious and have unusual ideas.
- They are independent and often prefer working on their own.
- They use information to support their ideas.
- They draw conclusions and bring new solutions.
- They are able to link seemingly unrelated things into a meaningful unit.
- They are creative.
- They want to know how things work.

The purpose of their research was to investigate whether Inquiry-based learning motivates gifted students. They used the method of design-based research. Initially, as a first step in the method they used, they investigated the needs of gifted students using a questionnaire, their sample was 15 gifted students aged 15-18 years old. Students' responses revealed the characteristics that these students seek from the learning process. These included experimentations, taking measurements, observation, data analysis, problem solving, formulating and contrasting opinions etc. Then, as a second step, they compared the needs of the students with the characteristics of Inquiry-based learning to see which of these characteristics they should retain and which to modify. From this process it became apparent that the components of the Inquiry-based model are compatible with the needs of gifted students, so they created teaching material incorporating compatible features. To evaluate the material produced by the previous process 50 teachers used the material in their classrooms in Czech republic. 45 gifted students attended these classrooms. According to the results of the research, inquiry-based learning is suitable for the education of gifted students because its characteristics are in line with their needs.

I Co-Building Knowledge and Collaboration

Social learning environments play a central role in inquiry-based/ constructivist pedagogy, co-building knowledge requires social skills [17, 21]. But according to the literature gifted students seem to prefer to work alone.

French *et al.* challenged the hypothesis that gifted children prefer to work alone, examining whether their children's preferences are modified according to the way in which the activity they are asked to perform is expressed [22]. The results of their research showed that although charismatic students often choose to work on their own, this choice was more frequent when the activity they were asked to carry out was traditionally formulated (e.g. multiple-choice questions), while the choice of solitude receded when the activities were open-ended.

In a more recent study, French *et al.* investigated whether the choice of gifted students to work alone is related to the form of questions they are asked to complete, their sense of support from the learning environment, and whether this choice is unanimous or influenced by factors such as age and gender [23]. 247 students, from united states, of all ages participated in the survey of which 111 were gifted and 44 were high achieving students. Their results suggest that gifted students do not necessarily prefer to work alone and that their preference largely depends on how much they feel supported in their learning by teachers and fellow students.

II Complexity and Expanding of Ideas

Kanevdky studied the preferences in the context of differentiated teaching of 416 gifted students and compared them with the preferences of 230 non-gifted students [24]. They used a questionnaire with 110 queries, on a five-point Likert-type scale, in order to determine the preferences for features of learning experiences. According to the results of their research, although there was no differentiation between the two groups in differentiated teaching features such as being given the opportunity to work at their own pace, choose their partner and choose the subject to consider, gifted students have chosen in their vast majority that they prefer to study complex and authentic problems inspired by their daily lives.

Scager *et al.* realizing that high-ability students perform better when challenged [25]. Raising the level of difficulty is simply not enough for these students, as they differ qualitatively from the general population of students (better memory, quick thinking, preference for complexity). They investigated the factors constitute challenge or a lack of it and to specify how challenge is established in the learning environments in six honors courses from all three years in the University College Utrecht. To collect their data, they interviewed students from all six courses. By analysing their responses in terms of three axes found in previous studies to play major role in students' motivation, autonomy, complexity and teacher expectations they have come to the conclusion that although students experienced the highest levels of challenge when three factors occurred simultaneously, complexity in particular was the factor that was most cited by students as the factor that primarily motivated them.

As the literature suggest, gifted students prefer complex problems and expanding of ideas. That is the essence of the inquiry-based learning. In Inquiry-based learning, students are free to deal with complex problems in novel ways. Problem identification, the most creative and interesting phase of the inquiry-based learning process, arises when the learner devises a central question whose answer gives the full explanation [26]. These features of exploratory learning fit gifted students learning style.

III Expertise

How quickly a piece of knowledge is recalled from memory is related to how well organized this knowledge is. How the various information are interconnected but also how they are linked to general categories evoke memory and recall. Experts on S.T.E.M. fields develop certain skills during the procedure of being an expert. Those kinds of skills are similar to Gifted students' skills. Coleman and Shore compared the cognitive process in physics problem solving between high performance students, average performance students and experts [27]. 21 students took part on the survey, with half of them being the high-performance group and the other half being the average performance group. A high school physics teacher, a Ph.D. and a M.Sc. student in physics where the expert group.

Five physics problem in increasing order of complexity where presented to each subject, then they were asked to verbalize their thoughts while solving the given problems. Each session was recorded. According to their results high performers high school students perform similar with experts in physics problems. In particular, the high performers in this study accurately monitor and evaluate their own problem-solving processes and immediately refer to relevant information that they previously learned in order to help them solve the problems.

Pelletier and Shore pointed out that some of the characteristics that gifted students seem to develop during the process of acquiring specialized knowledge are,

i. Adaptability (categorizing or rearranging problems into groups to focus on overall solutions.)
ii. Metacognition (executive function and self-regulation)
iii. Strategic planning (long pauses in the early stages of problem solving)
iv. Preference for complexity and the development of new problems
v. Greater memory skills (developing automation in key processes and releasing their working memory to address essential issues) [28].

All of these characteristics are characteristics of giftedness that are associated with the development of expertise through inquiry-based learning.

IV Self-Regulation and Flexibility

The metacognition, the clear awareness and conscious manipulation of ideas, skills and learning processes are important for the successful execution of difficult tasks. Shore conducted a number of studies at all levels of education in order to determine how gifted students thinking style is different from other students [29]. According to their results gifted students develop metacognitive skills more efficiently than ordinary students. These include metacognition, strategy flexibility, strategy planning, the use of hypotheses and the hierarchical and extensive webbing of knowledge about both facts and procedures. The high performance of gifted students is associated with the existence of a larger repertoire of metacognitive skills and strategies as well as their flexible and selective use of those strategies.

Gifted students have a wide range of problem-solving strategies to monitor, evaluate, and correct their thought processes flexibly during problem-solving. These are exactly the skills that inquiry-based learning aims at. Knowledge through inquiry is not acquired through the repetition of problems that are similar to each other (as is the case in the traditional way of teaching). In exploratory-type activities, students must gain a high level of understanding of the complexity of solutions in order to achieve high performance.

Training in Stem Related Topics and Gifted Education

Ramli *et al.* examined the use of educational robotics in a summer camp program which was designed to encourage young, gifted students to pursue science and technology education [30]. 48 students were selected to join the robotics class for a 3 weeks period. They have used Lego NXT-G kit in order to build and program various robots suitable for a number of occasions. According to their results the children were able perform an extensive programming skills of NXT-G, building a various types of complicated robots, self confidence in demonstrating and presenting their work as well as interactive social skills between them.

Mullet *et al.* conducted a research in order to determine the way gifted students perceive their progress through school education in STEM fields, but also how those experiences have impacted their STEM aspirations and talent development [31]? They used phenomenography research approach to identify the structural framework that describes gifted students perceptions. They conducted in-depth interviews of 7 first year students on the Honors College. Two of them were male and five were female. The interviews who lasted an hour for each participant were recorded and then were transcribed by a professional. They used a 5-stage analytical framework in order determine six major categories of meaning describing these gifted students 'conceptions of their advanced secondary S.T.E.M. education. According to their analysis the first major category is the Learning Environment in terms of Intellectual Challenge, Epistemological Orientation, and Academic Freedom. The second category is Institutional Supports, in terms of Organizational Obstacles, Diversity and Academic and career counseling. The third is Social support in terms of both students grouping and Teacher support. The fourth is Teacher qualities such ass interaction style, teacher competence and awareness of students' needs. Fifth category is active involvement in learning STEM and last Self-Perceptions of STEM Capability. As far as the second research objective is concerned all students took AP STEM courses and passed the exams However, only three students committed to majors in STEM, the other four students, all female, chose majors in other fields.

Jagust *et al.* examined the role of a series of educational robotics courses in skills development for gifted students. 15 gifted students aged 8-10 years old took part in the courses [32]. Typically, students worked in pairs, cooperating or collaborating on a solution to the given task. The courses were designed as "learning through experiment" activities. The activities that the students were called to complete were activities of free inquiry. As the activity requirements grew, more complex concepts from sciences, programing and mathematics were introduced. According to their findings, through these courses gifted students tent to be more creatively productive, as they often suggested solutions to problems were authentic and highly creative. They are focused and task oriented "speed learners" since they easily understand the concepts of science and mathematics. Also gifted students tent to be more motivated and independent and like to collaborate if they share the same specific interests and domain specific skills.

Miller *et al.*, recognizing that there is a link between different areas of science and spatial skills, and the fact that students' increased spatial skills are associated with increased interest and success in science, tried to measure the impact that spatial education would have on freshman gifted students [33]. A total of 77 first year students (28 women, 49 men) took part in the research. Half of them were assigned to a training condition of spatial training, six hourly sessions once a week for 6 weeks. The other half was the control group which did not participate in any form of training. All students took part in a test measuring their spatial skills prior training, one week after the last training session and 8 months after training. According to their results spatial training did improve spatial skills of the students immediate after the training, while also reducing gender differences in performance of spatial skill tests. The training group performed significantly better in introductory physics courses but there was no difference in the performance for other S.T.E.M. related courses. Lastly according to the posttests after 8-10 months there was no difference in performance between the two groups suggesting that spatial training is effective when is continues.

Based on the view that inquiry-based activities in STEM fields have a positive effect on young, gifted students, Robinson *et al.* developed a series of interventions in the form of problem-based units and trained 70 elementary teachers in the application of this educational material [34]. The basic idea was that teacher training was necessary to enable the intervention to be implemented correctly and then to measure its impact on gifted students. During the design of the educational material, emphasis was placed on developing problem-solving skills and also scientific research and experimental design skills. Emphasis was also placed on the development of activities focusing on the interdisciplinary approach of the issues. The intervention lasted a total of two years. 87 gifted students participated in the first year and 67 students in the second year in the intervention group, while 70 gifted students in the first year and 60 students in the second constituted the control group. According to their results students' performance in the treatment group was significantly improved in all three areas measured, which were science process skills, science content knowledge and science concept knowledge.

Conclusion

Our research shows that the characteristics of inquiry-based learning are effective for gifted students. Gifted students like to work together when they feel they are in a supportive environment, and they get excited when the activities involved are complex. Through inquiry-based activities they further develop their metacognitive skills while giving them the opportunity to develop all these skills that make them experts in the field they are training (adaptivity, strategic planning etc.). In addition, the literature shows that the application of activities in S.T.E.M. related topics such as robotics is particularly effective in educating gifted children as it enables them to approach learning in an interdisciplinary and holistic way, which is compatible with the learning preferences of those children.

References

1. Sanders M (2009) STEM, STEM Education, STEM mania. *Technol Teach* 20-27.
2. Zeidler DL (2016) STEM education: A deficit framework for the twenty first century? A sociocultural socioscientific response. *Cult Stud Sci Educ* 11: 11-26.
3. English LD (2016) STEM education K-12: perspectives on integration. *Int J STEM Educ* 3: 1-8.
4. Li Y, Wang K, Xiao Y, Froyd JE (2020) Research and trends in STEM education : a systematic review of journal publications. *Int J STEM Educ* 11: 6.
5. Li Y (2014) International Journal of STEM Education - a platform to promote STEM education and research worldwide. *Int J STEM Educ* 1: 1-2.
6. Morrison J (2006) TIES STEM education monograph series, attributes of STEM education. *Baltimore, MD: TIES*.
7. Toulmin CN, Groome M (2007) Building a science, technology, engineering, and math agenda. *Natl Governors Assoc*.
8. Council E (2015) National STEM school education strategy, 2016-2026. *Educ Counc*.
9. Bybee RW (2010) Advancing STEM Education: A 2020 Vision. *Technol Eng Teach* 70: 30-35.
10. Bruner JS (1960) The process of education. *Harvard University Press*.
11. Dewey J (1986) Experience and education. *Educational Forum* 50: 241-252.
12. N R C C on U. S. Education (1997) Science teacher preparation in an era of standards-based reform. *Nat Acad Press*.
13. N. C. of T. of M. C. on S. for S. Mathematics, Curriculum and evaluation standards for school mathematics. Natl Council of Teachers of, 1989.
14. Graham KJ, Fennell F (2001) Principles and standards for school mathematics and teacher education: Preparing and empowering teachers. *Sch Sci Math* 101: 319-327.
15. National Science Foundation (U.S.). Division of Elementary, Secondary, and Informal Education (1999) Inquiry: Thoughts, Views, and Strategies for the K-5 Classroom. *Nat Sci Found* 2.
16. Kay K, Greenhill V (2011) Twenty-first century students need 21st century skills," in Bringing schools into the 21st century. *Springer* 41-65.
17. MacLeod KJ (2010) Inquiry in Education, Volume I: The Conceptual Foundations for Research as a Curricular Imperative/Inquiry in Education Volume II: Overcoming Barriers to Successful Implementation. *Can J Educ* 33: 271.
18. Clark C, Shore BM (2004) Educating students with high ability. *Unesco*.
19. Robinson A, Shore BM, Enersen DL (2006) Best practices in gifted education: An evidence-based guide. *Sourcebooks Inc*.
20. Josef T (2014) IBSE and Gifted Students. *Sci Educ Int* 25: 19-28.
21. Vygotsky LS (1980) Mind in society: The development of higher psychological processes. *Harvard University Press*.
22. French LR, Shore BM (2009) A reconsideration of the widely held conviction that gifted students prefer to work alone. *Routledge Int companion Gift Educ* 176-182.
23. French LR, Walker CL, Shore BM (2011) Do gifted students really prefer to work alone? *Roeper Rev* 33: 145-159.
24. Kanevsky L (2011) Deferential differentiation: What types of differentiation do students want? *Gift Child Q* 55: 279-299.
25. Scager K, Akkerman SF, Pilot A, Wubbels T (2013) How to persuade honors students to go the extra mile: Creating a challenging learning environment. *High Abil Stud* 24: 115-134.
26. Lorentson M, Oh YJ, LaBanca F (2014) STEM21 Digital Academy Fidelity of Implementation: Valuation and Assessment of Program Components and Implementation. *Implement Fidelity Educ Res Routledge* 67-99.
27. Coleman EB, Shore B (1991) Problem-solving processes of high and average performers in physics. *J Educ Gift* 14: 366-379.
28. Pelletier S, Shore BM (2003) The gifted learner, the novice, and the expert: Sharpening emerging views of giftedness. *Creat Intell Towar Theor Integr* 237-281.

29. Shore BM (2004) Metacognition and flexibility: Qualitative differences in how gifted children think. *Talent Unfolding Cogn Dev* 167-187.
30. Ramli R, Md Yunus M, Ishak NM (2011) Robotic teaching for Malaysian gifted enrichment program. *Procedia- Soc Behav Sci* 15: 2528-2532.
31. Mullet DR, Kettler T, Sabatini AM (2018) Gifted Students Conceptions of Their High School STEM Education. *J Educ Gift* 41: 60-92.
32. Jagust T, Cvetkovic Lay J, Krzic AS, Sersic D (2017) Using robotics to foster creativity in early gifted education. *Int Confer Robotics Educ RiE* 126-131.
33. Miller DI, Halpern DF (2013) Can spatial training improve long-term outcomes for gifted STEM undergraduates? *Learn Individ Differ* 26: 141-152.
34. Robinson A, Dailey D, Hughes G, Cotabish A (2014) The Effects of a Science-Focused STEM Intervention on Gifted Elementary Students' Science Knowledge and Skills. *J Adv Acad* 25: 189-213.