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DEVELOPING SCIENTIFIC THINKING SKILLS: A LITERATURE REVIEW

Joanne M. Nazareno
Teacher II, Department of Education Philippines
Taytay Elementary School
Taytay, Rizal
joanne.nazareno001@deped.gov.ph

ABSTRACT

One of the main goals of science education is to empower individuals to think scientifically. Scientific thinking is a life skill that is helpful in developing solutions in any situation (Rother, 2017). Therefore, it is an essential skill for everyone especially now that the world is facing lots of environmental, health and socioeconomic problems (Cloude et. al, 2020). Dunbar and Klahr, 2012, described the two kinds of scientific thinking - one takes place when people think about things and processes that involve science content while the other is manifested as one performs a set of reasoning processes and methods involved in the field of science. This paper reviewed different journals, articles and studies conducted focusing on the development of scientific thinking, what it is all about, how it develops, taught, and measured among individuals, from preschoolers, to undergraduate students, interns, as well as staff members in a workplace, for the past ten years (2011-present). Based on the materials reviewed, developing scientific thinking skills among individuals is a complex process though it can be taught and developed in various ways. However, the means of measuring it is still a challenge for many educators and researchers. Moreover, teacher training for effective implementation of scientific processes and development of scientific thinking is recommended.

Keywords: Scientific thinking, science process skills, teaching-learning process

INTRODUCTION

In recent years, there have been many studies conducted related to scientific thinking. What is scientific thinking? Dunbar & Klahr (2012) defined Scientific thinking as thinking of science content together with the set of reasoning processes involved in science. These include induction and deduction methods, designing an experiment, informal reasoning, formulating a concept, testing a hypothesis, etc. While Rother (2017), described it as thinking that involves a comparison between what you predict will happen next, seeing what happens, and adapting based on what you learn from the difference. It is learning a way of thinking that makes a person better at problem solving which is a very essential skill in the 21st century.

This topic is very important in improving science education and learners' performance not only in science but in other subject areas as well. Skill in scientific thinking was also proven beneficial in a workplace. With scientific thinking skills, challenges are not impossible to meet and hence any goal can be achieved as a team or within a team (Rother and Rosenthal, 2018). Thus, it is something that needs to be developed in every individual so one can succeed not only as a student but as a significant part of a society.

This literature review will discuss answers to relevant questions about scientific thinking such as, “How does scientific thinking develop?”, “Can it be taught?”, “Can it be developed using games?”, “Can it be measured?”, and “Why is it important to be practiced and developed in every individual?” all of which are vital information that can help educators, learners, parents, and the community.

DISCUSSIONS

Concept and Importance of Scientific Thinking

Magno (2011) found out from his study that four domains are involved in scientific thinking. These are practical inclinations, analytical interest, intellectual independence, and discourse assertiveness which were derived through factor analysis and have significant positive correlation with each other. The insight gained from his study on scientific thinking leads to advance awareness in science education wherein the curriculum is pitched in improving students who would be involved in science work. He also stated that research conducted in the previous years emphasized the development of scientific thinking across science curriculum. Further, intervention must clarify and refocus on knowledge, skills and attitudes that are needed to be developed to attain success in science and the derived model of scientific thinking can be used as a set of traits that provide standard for students to develop.

According to Zimmerman & Klahr (2016), sophisticated scientific thinking encompasses the cognitive methods involved in stating questions, formulation of hypotheses, conducting investigations, creating models, designing experiments, assessing evidence, and building explanations, as well as a meta-level awareness of when, how, and why one should engage in these practices.

Scientific thinking skills involve observation, asking questions, making predictions or hypotheses, testing ideas or experimentation, recording data and communicating thoughts and results. Getting young children to be engaged in scientific thinking can lead to growth and learning not only for themselves, but also for those who interact with them (Larm & Jaros, 2017).

Rother & Rosenthal (2018) proposed that thinking scientifically is essential to avoid getting misled by human tendency to jump to conclusions in navigating unpredictable directions and for effective decision-making. Likewise, it may be a prerequisite for successful empowerment. The authors emphasized in their article that for learners to get the basics, they should begin with a common set of starter practice routines or “Starter Kata” which will soon lead to the development of a shared set of scientific thinking skills among individuals in a team. They concluded that even though performing new skills entails effort and some inconvenience at the beginning, the more scientific thinking ability developed within teams, the more they are empowered to meet challenges that may have once seemed very difficult.

According to Perjan & Sanduleac (2018), scientific thinking is a vital component that serves as a foundation in scientific and professional growth of university students. It is a process that enables scientific inquiry, and has been the source of both technological advantage, economic and social well-being globally. However, the problem of its development in students was first revealed in the 20th century when students face incidents that are consistent with their professional targets but there are no activities focused on scientific thinking development. In their study, they suggest that creativity, talents, behavior, personality traits, are few of the many factors that contribute to the development of scientific thinking, and these can be split up into intrinsic and extrinsic factors. Examples of internal factors are personality traits or experience while the extrinsic factors are primarily related to the external or natural environment. Further, the authors explained that there are factors that encompass the natural development of scientific thinking and are closely associated with psychological developmental features and elements that involve artificial intervention in scientific thinking development. Thus, signifies an organization on formation of scientific thinking and hence, can be divided in three main units: operational side, intellectual aspect, and personality components.

Scientific thinking does not develop independent of society and cultural means. Metacognitive capabilities (knowledge and understanding of your own thinking) represent one of the ways in which individuals differ and are necessary indicators of modern scientific thinking. When children have metacognitive control over the processes involved, they can change what they think based on evidence. Hence, they are not only mindful that they are changing an idea, but they also know why (Zimmerman & Klahr, 2018).

Hendrich et al. (2018), propose that a fundamental ability for food science professionals is the ability to convey scientific information to clients, other scientists, managers, and the society. This ability to communicate scientific information is the ability to think like a scientist.

Teaching Scientific Thinking

In their study, Carbajal et al. (2011) made use of robots to promote scientific thinking. The result was students had fun and were fully engaged during the activity and they were able to create models, hypotheses, and interesting experiments. The authors revealed that during the activity no group was able to come up with the correct solution to the given problem, though one group were able to propose an idea which proved that students were challenged and were able to construct their own hypothesis based on the hands-on device. Students' determination and initiative were evident when they were told about the activity. Indeed, this kind of activity requires additional work and preparation for teachers but according to the authors, it was worth it and they were encouraging other teachers to make an effort and try.

In the study conducted by Santana & Arroio (2011), they suggest that an active learning environment where students construct personal associations within their classroom experiences and the society is the aim of science educators. For this reason, students were encouraged to communicate scientific concepts using computers in a social context through comics. This strategy allowed students to be engaged with the science concept through interaction with the computer. They were encouraged to seek information from the internet and ask questions during the activity which resulted in understanding, positive motivation and integration of using information and communication technology tools and skills as well. Moreover, the authors believed that developing implications for increasing student understanding is possible even in fun but challenging activities.

Application of science concepts to real-world challenges allows students to obtain deeper understanding of content and promotes critical thinking skills needed for them to become productive members of society (Jones, 2012).

Al-Ahmadi & Reid (2012) suggested based on their study that understanding scientific thinking is possible when appropriate teaching strategies and environment are applied though it may be accessible only when the student is about the age of 16 for it could be the minimum age before understanding hypotheses and experimentation.

Morris et. al (2012) argued that scientific thinking skills do not typically develop and must be supported by educational and cultural tools. They suggest that science education can be enhanced by integrating elements of games that impact the three classes of mechanisms which are motivation, cognitive and metacognition. Examining game features and their relation to developmental procedures can be done to effectively promote science education.

Based on the theoretical model presented by Perjan & Sanduleac (2012), scientific thinking can be developed only if certain circumstances and principles are recognized. In the beginning, there are some elements that cannot be ignored, and which are strongly related with every part of scientific thinking, specifically scientific knowledge, skills, capacity of reasoning and understanding, metacognition, and finally the scientific methods, all interdependent with one another. The critical thinking as the operational component is in direct proximity to scientific thinking, being the basic operational component that assures the good functioning of scientific thinking. At the base of the model stay personality peculiarities that form a solid base consisting of attitudes, beliefs, orientation.

Zimbardi et al. (2013) discovered in their study that vertical integration of inquiry-based practical curriculum has a significant effect on student learning within a wide range of domains. Aside from the expected learning achievements in advanced scientific thinking skills and the principles for scientific communication, students also recounted learning a great deal of discipline-specific content aligned and extended on their lecture material. Therefore, the said curriculum serves as useful standards on how to support early-stage undergraduate students with properly adapted skills and levels of independence that improve their scientific communication and scientific thinking skills and accordingly make them positively and successfully face the complex, new problems they will encounter in the 21st century workplace.

The study on self-regulated learning as a method to develop scientific thinking conducted by Peters-Burton (2013) where self-regulation cycle was done in three phases, the forethought, performance, and self-reflection, revealed that establishing objectives on more complex scientific thinking was tough for students because they only had slight interaction with the characteristic rules that drive the scientific endeavor. It was suggested that teachers assist their students in setting their own objectives for scientific thinking by being specific on the function of science and the scientist while the teachers also set standards that enable students to monitor their own performance during the learning activity and make self-evaluation afterwards as well.

Zimmerman (2014) stated in her article that video games which are aimed at keeping players involved, likewise result in having determination, extended time-on-task, lack of fear of failure, leveling up and mastery approaches are all attributes that educators would also love to develop among students. She suggested that new generation of games that include elements such as problem-solving, self-directed experimentation, hypothesis testing and causal reasoning, which are all relevant to scientific thinking.

Zeidler et al. (2015) suggested that advocating responsible scientific thinking intends to promote conscientious scientific practices for all students which requires both technical competency and ethical behavior within the scientific society. Students are expected to be attentive and determined when performing any task and finally develop character through responsible scientific thinking.

Findings suggest in the study conducted by Pfefferová (2015) on the Development of Scientific Thinking of Students through Simulations that the use of simulations accompanied by the worksheets for the student and the teacher had a great impact on students' knowledge in physics in the experimental class. Correspondingly, the use of simulations offered students a lot of opportunities in getting engaged unlike in the traditional teaching. Further, it also lets students work independently while improving their abilities to work in a team. Hence, the author proposed that the use of simulations is effective in the teaching-learning process and in developing scientific thinking among students.

Kapici et. al (2017) suggested that it is imperative that students learn concepts and use them in problem solving and further understanding. Science education must be multi-dimensional which includes conceptual understanding and application in real life, acquisition of science process skills giving emphasis to the nature of science. The extent of application or transfer of knowledge especially in daily life events and concrete and new situations indicates new learning and understanding.

Har (2017) proposed that providing the facilities of learning and improving the quality of teachers should receive high attention.

At present, where accurate information is given less emphasis and many students are having difficulty in recognizing print, online and media information, it is very necessary to educate and encourage them to think scientifically. Lack of awareness of the nature of science holds significant repercussions throughout the world. (Schmaltz & Lilienfeld, 2017)

Science education researchers claim that any experiment must be performed by considering precise questions and insightful discussions and with the objective to attain conclusions about them. In this case, students can in fact participate in data-theory coordination by providing them further understanding and various instances that make use of scientific thinking (Gasparatou, 2017).

Salem & Al-Doulat (2017) studied the effect of teaching using the STEM approach in the acquisition of scientific concepts and developing the scientific thinking among classroom-teacher students. The respondents of the study were divided into two groups - the study group where the STEM approach was applied and the control group which used the ordinary teaching method. Findings of the study indicate that there was a statistically significant effect of teaching using the STEM approach in the development of scientific thinking for the students under the experimental group and they had better performance than the control group who studied and learned the usual method. The authors explained that using a multidisciplinary approach in teaching enables students to solve problems using combined knowledge and skills in science, technology, mathematics, and engineering. Thus, they recommend the application method in accordance with the STEM course together with a pleasant and encouraging learning environment for students to be experts in scientific thinking process.

Wyeth & Wonham (2018) found it useful to teach the Question-Hypothesis-Test (HQT) cycle step by step, starting with students' observations followed by asking questions, hypotheses, and tests. They claimed that at first when students begin to apply the scientific method to their own research, they readily understand the idea of each stage (observations, questions, hypotheses, and tests) but in the implementation they experience certain reasoning difficulties. However, with the use of the Question-Hypothesis-Test (QHT) framework, students are well prepared to employ the scientific method as they develop their own independent work.

Udoye et al. (2018) conducted a study on the development of scientific thinking through educational multindi (multicultural-individualism) which proposes that same modes (selves) of environmental, physio-biological, cognitive, affective, and spiritual selves, collectively called epcas-self, are used in understanding and interpreting the environment, the interaction between modes, and multindi in understanding and interpretation. Findings of the study revealed that developing the epcas-self for multindi education helps Nigerian students to integrate and develop scientific thinking as he/she trains to participate in the labor market. They recommended that classroom teachers, irrespective of subject taught be attentive to epcas-self development of Nigerian secondary school students.

Klahr et al. (2018) emphasized the three primary aspects of the essential goals of science education - first is promoting conceptual thinking in science which aims to teach children something about scientific knowledge, second is promoting procedural thinking in science which means teaching students some of the fundamental processes of science, and third is promoting the ability to utilize “School Science Knowledge” to “Everyday Scientific Thinking” which encourages students to use what they have learned about scientific products and scientific processes in their daily lives.

Hosein & Rao (2019) argued that for the students to develop scientific thinking skills the teacher shall design the curriculum specifically the research methods courses that support students to the aspects of self-determination theory (SDT) in students’ learning.

Instructional frameworks can help learners think more critically, enable scientific judgments, and strengthen their science knowledge in classroom situations (Lombardi, 2019).

In the study conducted by Martinez and Balderrama (2019), they found out that the level of achievement of students was directly associated with their commitment in performing the science activities such as a research before the experimental activities, approach to the inquiry question, experimental design and procedure and formulation of proposals and the report like the experimental diagram. However, the success or failure of students does not rely only on themselves. Students need dedicated teachers who really know about this teaching-learning strategy, teachers who can introduce science content creatively and innovatively and who are able to design activities and assessment procedures that are challenging for the students so they can develop skills in scientific thinking.

Rind & Ning (2020) argued that a great deal of scientific thinking and scientific theory construction has something to do with the development of causal models between variables of interest. The authors suggest the most common strategy used in science education for the causal models is known as Control of Variable (CoV) which is integrated in the national curricula of science education of numerous developed countries. This concept and its main function in doing science is usually presented in early grades through a simple experiment.

Jirout (2020) suggested specific strategies that may promote children’s curiosity which could support early scientific thinking. First is to encourage and provide opportunities for children to explore with proper guidance and support. Second is to model curiosity and show how enjoyable information-seeking activities are. Third, encourage deeper questioning by using explicit prompts and supporting children to generate questions. Lastly, by promoting and reinforcing children to think about alternative ideas, which could also support creativity.

Al-Saadi & Al-Ijrash (2020) conducted a study to find out the effectiveness of Modern Models (the John Zahorik and Woods model) in the achievement of academic subjects as well as the development of scientific thinking among fourth grade students in the Faculty of Basic Education. Findings revealed that Woods and Zahorik models have positively affected the achievement of students in the curriculum and textbooks, which implies that these models are effective in the teaching-learning process. Likewise, the said model had a clear impact on the performance of students in terms of scientific thinking. The authors also propose that using these models enhances the collaboration and active participation of students in classroom activities.

Due to the decrease in student internship brought about by the serious academic and social disruption caused by COVID-19, Boury et al. (2021) created a unique internship for students majoring in biological sciences. The internship allowed students to systematically work together in categorizing and annotating several podcast episodes of TWiM (This Week in Microbiology). It turned out that by working together, interns developed their oral and written communication skills as well as their scientific thinking skills. Students stated in the interview that they gained confidence in analyzing and interpreting results from a variety of microbiological methods, improved oral and written communication on fundamental microbiology concepts, and enhanced their ability to work with others. The authors propose that the digital internship provided an exceptional opportunity for students to develop critical, technical, and scientific thinking skills while at the same time generating useful open education resources for teaching general microbiology in the form of annotated podcasts.

Svatava et al. (2021) created a framework of scientific thinking and reasoning that would meet the needs of knowledge-based companies operating in natural sciences. Through the qualitative analysis of interviews, it was found out that the proposed framework was a helpful tool for companies for they can easily identify the skills and abilities of their employees. The authors suggest that skills related to scientific thinking and reasoning go beyond the manufacturing industry and can be used in a wide range of occupations, even outside the field of natural sciences. Further, the authors recommend additional testing of the framework as it can serve as a communication tool and in distinguishing individual skills suitable for specific work positions.

Measuring Scientific Thinking

Thitima & Sumalee (2012) conducted a study which aimed at examining scientific thinking of the learners under the knowledge construction model of enhancing scientific thinking. Findings suggest that the model promotes students' team learning ability and that the learners' scientific thinking abilities consist of inquiry, analysis, inference, and argument.

In the study conducted by Delaney et al. (2015) a new test format was developed to assess students' skills in scientific thinking using an online multiple-choice (OMU) test which was given after a practical activity or experiment wherein they are supposed to gain knowledge or enhance their pre-knowledge about the concept. The test items used were clustered into four areas, with items of different difficulty levels for each group. The first one is designing a controlled experiment, second is interpreting data from a graph, table or a visual, third is drawing valid conclusions from experimental data and lastly, identifying errors in the design of an experiment. However, the online test administered after the practical activity does not use students' results from their experiment, but it requires them to answer questions related to the 'scientific methods' used therefore using only either their acquired knowledge or their enhanced pre-knowledge about the experiment to answer the OMU. Hence, the practical activity given beforehand to help them gain relevant knowledge and reinforce their pre-knowledge was not assessed itself. The authors also mentioned about a previous study which has suggested that using paper-and-pencil tests to assess scientific thinking does not associate well between planning and evaluating a controlled experiment and the performance-based assessment. Therefore, despite the perceived difficulties in its administration, performance-based tests were still recommended to assess scientific thinking.

Koerber et al. (2015) assessed the development of scientific thinking in elementary school using a 66-item scale where five components of scientific thinking were addressed, including experimental design, data interpretation, and understanding the nature of science. They found out that scientific thinking is a unitary trait that is separable from intelligence or general processing skills while the performance on the inventory confirmed that even in children as young as 8 years of age, scientific thinking assessed over different components is conceptually consistent.

Cloude et al. (2020) conducted a study to examine scientific thinking with game-based learning environments (GBLEs) to ascertain best possible features for individualizing instruction learning science. Their study aimed at investigating whether learners' multichannel data generated during game-based learning with Crystal Island were related to scientific thinking and performance and its possibility to be used to guide individualized instruction with GBLEs. Findings revealed that there's a significant predictive relationship between eye-gaze, pre-test scores, and interaction data related to scientific reasoning, indicating that eye-gaze, prior knowledge, and agency play a crucial role in scientific thinking and performance with GBLEs. Hence, the authors suggest that in order to boost learners' scientific thinking, learning, and performance with the use of GBLEs, learners' prior knowledge must be considered in designing the agency levels.

SYNTHESIS

Studies on the development of scientific thinking are of great significance to educators and researchers. Various problems arise when people become irresponsible, commit mistakes, or lack awareness of the things that should matter. One thing that we can do is to be mindful of every decision and action we make, especially when it is about our health and wellness, productivity, and environment conservation, and here is when we can apply scientific thinking. Scientific thinking skills consist of the traits, characteristics and thinking methods utilized by scientists to investigate and address problems in the natural world (McComas, 2014). Through the development of scientific thinking among individuals, people will acquire the knowledge, skills and attitudes of scientists who are always concerned in making things work, sustainable and better for the society. Hence, studies are conducted to eventually prepare individuals to become more scientifically literate so we can altogether solve and adapt to global challenges in this fast-changing world (Lombardi, 2019). Still, further research as well as training for educators are necessary to develop teachers' competence in the effective implementation of scientific approaches in the teaching-learning process and for them to successfully develop scientific thinking among their learners (Suciati et al., 2018). Indeed, scientific thinking is a complex process, though can be taught and developed in many ways, and aside from the field of science and technology it is very much applicable in solving daily life problems and adapting to various situations in a more systematic approach. Scientific thinking is certainly an indispensable skill for every individual that can help make the world a better place to live in.

REFERENCES:

Al-Ahmadi, F. & Reid, Norman. (2012). Scientific thinking. Can it be taught?. Journal of Science Education. 13. 18-24. Retrieved from https://www.researchgate.net/publication/292852114

Al-Saadi, Sahira Abbas Qanbar & Al-Ijrash, Haidar Hatem Faleh. (2020). The Effectiveness of Modern Models on the Achievement of Academic Subjects and the Development of Scientific Thinking among University Students. Retrieved from https://www.xajzkjdx.cn/gallery/197-mar2020.pdf

Boury, Nancy & Alvarez, Kanwal S. & Costas, Amaya Garcia & Knapp, Gwendowlyn S. & Seipelt-Thiemann, Rebecca L. (2021). Teaching in the Time of COVID-19: Creation of a Digital Internship to Develop Scientific Thinking Skills and Create Science

Literacy Exercises for Use in Remote Classrooms. Retrieved from https://journals.asm.org/doi/10.1128/jmbe.v22i1.2433

Carbajal, Juan & Assaf, Dorit & Benker, Emanuel. (2011). Promoting Scientific Thinking with Robots. Retrieved from https://www.researchgate.net/publication/51932605

Cloude, Elizabeth & Dever, Daryn & Wiedbusch, Megan & Azevedo, Roger. (2020). Quantifying Scientific Thinking Using Multichannel Data With Crystal Island: Implications for Individualized Game-Learning Analytics. Frontiers in Education. 5. 10.3389/feduc.2020.572546. Retrieved from https://www.researchgate.net/publication/345630327

Delaney, Seamus & Beerenwinkel, Anne & Labudde, Peter & Moser, Urs. (2015). Development of a new test format for a large-scale assessment of scientific thinking. Retrieved from https://www.researchgate.net/publication/313423190

Dunbar, Kevin & Klahr, David. (2012). Scientific Thinking and Reasoning. The Oxford Handbook of Thinking and Reasoning. 10.1093/oxfordhb/9780199734689.013.0035. Retrieved from https://www.researchgate.net/publication/285936617

Gasparatou, Renia. (2017). Scientism and Scientific Thinking. Science & Education. 26. 1-14. 10.1007/s11191-017-9931-1. Retrieved from https://www.researchgate.net/publication/320419661

Har, Erman. (2017). Contributions of Cultural Elements of Modern Science, Scientific Thinking Skills, Scientific Thinking Habits, to the Culture of Indigenous Science. Research Journal of Applied Sciences. Year: 2016 | Volume: 11 |. Page No.: 985-991. 10.3923/rjasci.2016.985.991. Retrieved from https://www.researchgate.net/publication/312315909

Hendrich, S., Licklider, B., Thompson, K., Thompson, J., Haynes, C. and Wiersema, J. (2018), Development of Scientific Thinking Facilitated by Reflective Self-Assessment in a Communication-Intensive Food Science and Human Nutrition Course. Journal of Food Science Education, 17: 8-13. https://doi.org/10.1111/1541-4329.12127

Hosein A., Rao N. (2019) The Acculturation and Engagement of Undergraduate Students in Scientific Thinking Through Research Methods. In: Murtonen M., Balloo K. (eds) Redefining Scientific Thinking for Higher Education. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-030-24215-2_7

Jirout Jamie J. (2020). Supporting Early Scientific Thinking Through Curiosity. Frontiers in Psychology Volume 11. page 1717. Retrieved from https://www.frontiersin.org/article/10.3389/fpsyg.2020.01717

Jones, R. A. (2012). What were they thinking? The Science Teacher, 79(3), 66-70.

Kapici, Hasan Ozgur, Akcay, Hakan & Yager, Robert E. (2017) Comparison of science-technology-society approach and textbook oriented instruction on students' abilities to apply science concepts. Retrieved from International Journal of Progressive Education, Volume 13 Number 2

Klahr, David & Zimmerman, Corinne & Matlen, Bryan J. (2018) Improving Students' Scientific Thinking. Retrieved from https://www.cmu.edu/dietrich/psychology/pdf/klahr/PDFs/9781108416016c04_p67-99-2.pdf

Koerber, Susanne & Mayer, Daniela & Osterhaus, Christopher & Schwippert, Knut & Sodian, Beate. (2015). The Development of Scientific Thinking in Elementary School: A Comprehensive Inventory. Retrieved from https://srcd.onlinelibrary.wiley.com/doi/abs/10.1111/cdev.12298

Lombardi, Doug. (2019). Thinking scientifically in a changing world. Retrieved from https://www.researchgate.net/publication/330738190

Magno, Carlo. (2011). A Measure for Scientific Thinking. The International Journal of Educational and Psychological Assessment. 6. Retrieved from https://www.researchgate.net/publication/277405386

Martinez, Kira Padilla and Balderrama, Jorge Luis (2019). Developing scientific thinking skills through teaching chemical reaction with inquiry based teaching. Vol. 30 No. 1 Page 106. Retrieved from http://revistas.unam.mx/index.php/req/article/view/64614

McComas, William F. (2014) THE LANGUAGE OF SCIENCE EDUCATION: An Expanded Glossary of Key Terms in Science Teaching and Learning, page 96

Morris, Bradley & Croker, Steve & Zimmerman, Corinne & Gill, Devin & Romig, Connie. (2013). Gaming Science: The Gamification of Scientific Thinking. Frontiers in psychology. 4. 607. 10.3389/fpsyg.2013.00607. Retrieved from https://www.researchgate.net/publication/256931992

Peters-Burton, Erin. (2013). Self-Regulated Learning as a Method to Develop Scientific Thinking. 10.4018/978-1-4666-2809-0.ch001. Retrieved from https://www.researchgate.net/publication/279854099

Pfefferová, Miriam. (2015). THE DEVELOPMENT OF SCIENTIFIC THINKING OF STUDENTS USING SIMULATIONS. Journal of Technology and Information. 7. 81-89. 10.5507/jtie.2015.006. Retrieved from https://www.researchgate.net/publication/284204351

Perjan, Carolina & Sanduleac, Sergiu. (2018). INCREASING THE QUALITY OF UNIVERSITY STUDIES THROUGH THE DEVELOPMENT OF STUDENTS' SCIENTIFIC THINKING. Applied Researches in Technics, Technologies and Education. 16. 195-201. 10.15547/artte.2018.02.017. Retrieved from https://www.researchgate.net/publication/332878210

Rind, Irfan Ahmed & Ning, Bo. (2020). Evaluating scientific thinking among Shanghai's students of high and low performing schools. The Journal of Educational Research. 113. 1-10. 10.1080/00220671.2020.1832430. Retrieved from https://www.researchgate.net/publication/344781535

Rother, Mike. (2017). The Toyota Kata Practice Guide: Developing Scientific Thinking Skills for Superior Results. Retrieved from https://www.researchgate.net/publication/318109888

Rother, Mike and Rosenthal, Mark. (2018). An Approach to Becoming Agile in a Dynamic World. Helping employees develop scientific thinking empowers them to solve problems and make decisions.. 34. Retrieved from https://www.researchgate.net/publication/325719370

Salem, Adnan & Al-Doulat, Adnan. (2017). The impact of teaching using the STEM approach in acquisition of scientific concepts and developing scientific thinking among Classroom-Teacher students at the University of Jordan. 147. Retrieved from https://www.researchgate.net/publication/319930771

Santana, Edson & Arroio, Agnaldo. (2011). COMICS: A TOOL FOR TEACHERS AND STUDENTS IN TEACHING AND LEARNING SCIENCE. GAMTAMOKSLINIS UGDYMAS / NATURAL SCIENCE EDUCATION. 8. 49-59. 10.48127/gu-nse/11.8.49a. Retrieved from https://www.researchgate.net/publication/351830306

Schmaltz, Rodney M. and Lilienfeld, Scott O. (2017). Editorial: Novel Approaches to Teaching Scientific Thinking: Psychological Perspectives. Retrieved from https://www.frontiersin.org/articles/10.3389/fpsyg.2017.00820/full

Svatava Janoušková, Lubomíra Pyskatá Rathouská, Vojtěch Žák & Eva Stratilová Urválková (2021): The scientific thinking and reasoning framework and its applicability to manufacturing and services firms in natural sciences, Research in Science & Technological Education, DOI: 10.1080/02635143.2021.1928048. Retrieved from https://doi.org/10.1080/02635143.2021.1928048

Suciati, M. N. Ali, C. D. Imaningtyas, A. F. Anggraini, Z. Dermawan. (2018). THE PROFILE OF XI GRADE STUDENTS' SCIENTIFIC THINKING ABILITIES ON SCIENTIFIC APPROACH IMPLEMENTATION. Retrieved from http://journal.unnes.ac.id/index.php/jpii

Thitima, Gamlunglert & Chaijaroen, Sumalee. (2012). Scientific Thinking of the Learners Learning with the Knowledge Construction Model Enhancing Scientific Thinking. Procedia - Social and Behavioral Sciences. 46. 3771-3775. 10.1016/j.sbspro.2012.06.144. Retrieved from https://www.researchgate.net/publication/271619077

Udoye, Ngozi & Nnorom, & Ughamadu, Uju. (2018). EDUCATIONAL MULTINDI: AN INTEGRATIVE AND COMPETITIVE DEVELOPMENT OF SCIENTIFIC THINKING AMONG NIGERIAN SECONDARY SCHOOL STUNDENTS. Retrieved from https://www.researchgate.net/publication/342530067

Wyeth, Russell & Wonham, Marjorie. (2018). Patterns vs. Causes and Surveys vs. Experiments: Teaching Scientific Thinking. The American Biology Teacher. 80. 203-213. 10.1525/abt.2018.80.3.203. Retrieved from https://www.researchgate.net/publication/323662325

Zeidler, Dana & Applebaum, Scott & Sadler, Troy. (2015). Thinking Scientifically ZeidlerBerkowitzBennett 040511[2]. Retrieved from https://www.researchgate.net/publication/274510394

Zimbardi, Kirsten & Bugarcic, Andrea & Colthorpe, Kay & Good, Jonathan & Bryan-Lluka, Lesley. (2013). A set of vertically integrated inquiry-based practical curricula that develop scientific thinking skills for large cohorts of undergraduate students. Advances in physiology education. 37. 303-15. 10.1152/advan.00082.2012. Retrieved from https://www.researchgate.net/publication/259110283

Zimmerman, Corinne. (2014). Developing scientific thinking in the context of video games: Where to next?. 10.1093/acprof:osobl/9780199896646.003.0005. Retrieved from https://www.researchgate.net/publication/283723633

Zimmerman, Corinne and Klahr, David. (2016). Development of Scientific Thinking. The Stevens' Handbook of Experimental Psychology and Cognitive Neuroscience, Fourth Edition. Retrieved from https://www.cmu.edu/dietrich/psychology/pdf/klahr/dev-of-scientific-thinking-stevens-hndbk.pdf

Zimmerman, Corinne & Klahr, David. (2018). Development of Scientific Thinking. 10.1002/9781119170174.epcn407. Retrieved from https://www.researchgate.net/publication/324272107