Effect of Analogies on Developing Understanding of Concepts of Geometry

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Abstract

Students of any level always find concepts of geometry to be challenging. Poor conceptual knowledge is the cause of poor performance in geometry. In the current study, grade eight students' comprehension of geometry concepts was improved by the use of analogies as a teaching method. The research study was quasi-experimental in nature and employed a Nonequivalent Control group design. The sample of the study consisted of two intact groups: the experimental (N = 33) and the control (N = 35). The schools included in the sample were selected randomly from among high schools where the researcher could seek permission to conduct the study. The tool was a self-developed achievement test based on a chapter from the eighth-grade math textbook. According to the study's findings, students were able to define and clarify geometrical concepts in their own terms, as well as connect and apply those concepts to everyday situations, by using analogies. This demonstrated unequivocally that the pupils' grasp of the concepts of geometry was developed through the usage of analogies.

Keywords: Analogies, Concept understanding, Concepts of Geometry

Introduction

Merriam-Webster online dictionary and thesaurus says that an analogy is the act of comparing two things that are similar in some manner, usually for the purpose of explanation or clarity. Originating in ancient mathematics, the term analogy denotes the equality of two ratios (Loc, 2015). It is a two-word relationship that contrasts two objects that are unlike in other ways but share one or more characteristics. Put otherwise, analogical reasoning is the

mental transfer of meaning from one subject (the source) to another (the target). An analog from which conclusions or explanatory frameworks are derived is called the source or base. It is the more recognizable or tangible field. The target is an analog from which conclusions are being drawn. It's a more ethereal or unfamiliar domain. For instance, the plumbing system is the more physical and therefore more recognized domain in the analogy "an electric circuit is like a plumbing system," making it a source domain. However, electric circuits are less well-known or abstract, making them target domains (Gentner & Smith, 2012).

An analogy is a nonliteral comparison across knowledge domains that appear to be superficially diverse (Zook, 1991). This type of resemblance occurs when the same set of relationships remains true for various things (Gentner, 1998). Its purpose is to determine which features of one thing—also referred to as the source, base, or known domain—are comparable to which features of another—also referred to as the target or unknown domain. According to Gentner (1983) and Gentner & Gentner (1983) a structural mapping between the source and the target domain is what is meant by an analogy. Although there are differences between the source and target domains, structure mapping reveals similarities in the relational structure of the base and target domains. Analogies are an effective teaching tool. An attempt was made to employ this in the current study as well to develop knowledge of the geometric concepts.

Objectives of the Study

Following were the objectives of the study:

1. To determine the elementary students' baseline comprehension of geometry concepts.
2. To determine how well elementary students grasp geometry concepts through the use of an analogy-based teaching model.

Literature Review

Several research support the idea that using metaphors and analogies is a more effective way to promote conceptual transfer and understanding (Shana, & El Shareef, 2022; Gray, and Holyoak, 2021; Fotou, & Abrahams, 2020; Hidir, & DİDİŞ, 2018; Pitterson, Perova-Mello, & Streveler, 2018; Khan, & Mahmood, 2018; Khan, & Mahmood, 2017; Lee & Sriraman, 2011; Calik, Okur, & Taylor, 2011; Michael, 2003). Analogies are useful tools for teaching concepts because they allow one to compare the unknown with the known (DİDİŞ and Hıdır, 2019). Frequently used analogies in teaching are verbal, pictorial and personal. A verbal analogy is a piece of writing or spoken representation that is skillfully woven into the text. It is up to the reader to make the appropriate comparison. One kind of visual depiction that is typically used in conjunction with spoken explanation is the pictorial analogy. It enables a teacher or the author of the textbook to visually emphasize the desired qualities of the analog. In the personal analogy students feel as though they have become the object. This analogy can be used to relate abstract concepts to more relatable, daily life ideas (Thiele & Treagust, 1992).

Students who comprehend the intricacies of analogies are able to acquire superior intellectual comprehension (Fotou & Abrahams, 2020; Hidir & DİDİS, 2018; Mason, 1994). Additionally, a strong association was shown between the analogy's intended goal and mental comprehension of the scientific material (Braasch, and Goldman, 2010). This brings us to the

conclusion that analogy serves as a structural foundation for rearranging current knowledge in addition to facilitating assimilation of new information. Mason (1996) asserts that the following uses of analogies are beneficial when evaluating the role of analogical reasoning in restructuring scientific knowledge: (a) coding and organizing new knowledge; (b) accessing and retrieving previously stored information; (c) creating anomalies within a conceptual framework; (d) dispelling misconceptions; and (e) creating new schemata.

Analogies may lead to Misconception

Many studies support the idea that using analogies frequently may results in misunderstandings (DİDİŞ, 2015; Duit, Roth, Komorek, and Wilbers, 2001; Taber, 2001; Treagust et al., 1998, 1994; Thiele and Treagust, 1994; Harrison and Treagust, 1993, 2000). Analogies can be "double edged swords" (Glynn, 1994); depending on the situation, an analogy can both help and hinder learning. Duit (1991); Glynn, Duit, and Thiele, (1996) [as stated in Duit, Roth, Komorek, & Wilbers, (2001)]also demonstrated that analogies may not provide the expected outcomes and may even cause students' thought and learning processes to be misguided. According to Thiele and Treagust, pupils might not be able to distinguish analogy from the information they are sending because it may be a more extensive component of application. They go on to add that some students will focus on irrelevant details in the parallel and draw broad conclusions about the target material, while others will recall the similarity but forget the content (1992).

Dealing with the Misconception

When analogies are used improperly, they might lead to misunderstandings (Ryan, 2006). They are only misleading when there is a possibility that students won't be able to find a suitable relevant analogy, won't see the similarities between the taught target domain and the source domain, and won't see the points at which the analogy falls apart (Pitterson, et al., 2018; Haglund, 2013; Coley, & Tanner, 2012; Braasch, & Goldman, 2010). When applied methodically, analogous instructions help students eliminate misconceptions about a concept (BM de Almeida, Salvador, & Costa, 2014; Dilber & Duzgun 2008). Potential risks can also be reduced by teaching students how and when to apply analogies and what to do in the situation that the applied model is unable to accomplish their goals (Gokhan, Dilber, Senpolat, & Duzgun, 2012; Ryan, 2006). Additionally, educators need to thoroughly inform students of the similarities and differences between the source and target domains and assist them in finding appropriate parallel analogies. When applying an analogy does not produce the expected outcomes, students need to be taught how to use alternative methods. The teacher's constant observation and direction will prevent students from making mistakes. A methodology was proposed by Glynn, Yeany, and Britton (1991) to optimize the usage of analogies and decrease misinterpretation. This methodology requires a teacher to do the following:

i. Introduce the target concept (to be taught).
ii. Present the source or base concept, which will be utilized to illustrate how the target concept is similar.
iii. Carefully consider the pertinent aspects of both the source and the target concept.
iv. Point out the similarities.

v. Point out the differences.
vi. Make inferences.

The following is a concise summary, organized into different sections, summarizing the findings of earlier research:

i. Motivation: Students are motivated in the classroom when analogies are used. Students are prepared for the process with a number of relevant analogies drawn from their personal experiences. They take part in the procedure themselves. This raises their degree of motivation (Benkoski & Greenwood, 1995).

ii. Promotion of Visualization Process: By drawing relevant parallel analogies from their own experiences, students can also initiate and facilitate the visualizing process in the classroom (Thiele & Treagust, 1994; Iding, 1997).

iii. Concept Understanding: Use of analogy in the teaching-learning process places special emphasis on understanding of concepts. It enables students to redefine various concepts in their own words by analyzing and synthesizing different examples (Gay, 2008). They perform better and show increased immediate and delayed recall and long term retention Halpern, Hansen, & Riefer, 1990; Newby, Ertmer, & Stepich, 1995; Staple and Spears 1996; Venville & Treagust, 1996; Venille & Treagust 1997; Dahl & Moreau, 2002). Students in a study improved their understanding of the concept of capacity by using analogies (Szetela, 1980). Additionally, Halpern, Hansen, and Riefer (1990) attest that learning the concept of capacity through analogy is more beneficial.

Students can relate and apply concepts they have learned to real-world situations by using analogies (Middleton, 1991; Thiele & Treagust, 1994; Venville & Treagust, 1996; Gabel, 2003; Ramos, 2011). In a study, students were instructed to illustrate biological concepts using topics from daily life in a diagram using sheets of paper and pencils. They created these kinds of sketches:

- Cell (containing organelles): a city with streets, shops, and a government.
- Reproduction: To make fresh cookies, combine cookie dough and chocolate chips.
- Alcohol and drug use: these substances pollute the environment and generate environmental concerns;
- Body system: factories that process and transport materials (Middleton, 1991).

Using analogies helps students find relationships among different pieces of knowledge (Silkebakken & Camp 1993), which can help make concepts easier to understand (Halpern, Hansen, & Riefer, 1990), as well as serve as a guide for concept formation (Nersessian, 1998). Students can also analyze various concepts and identify similarities and differences for the purpose of explanation and can give various relevant meaning to concepts (Ramos, 2011).

In addition to teaching students new ideas, effective use of analogy allows them to view previously taught material in a different way (Middleton, 1991). They can create their own interpretation of the concepts (Stepich & Newby, 1988) or come up with fresh, and new idea about the concept (Dahl & Moreau, 2002).

Methodology

This study was quasi-experimental in nature and used a non-equivalent control group design. Two intact groups of eighth-grade students from two boys' high schools were selected randomly as sample of the study. Selected schools were representative of typical government

high schools. They were representative in terms of amenities, the school setting, the socioeconomic standing of the pupils, their family history, the qualifications of the instructors and the procedures involved in hiring and promoting them, and the availability of audiovisual aids.

Instrument

A self-developed achievement test in geometry was the study's instrument. The generated items served as representations for the geometric concepts. Additionally, all levels of cognitive domain of Bloom's taxonomy were taken into consideration when developing the items. The instrument's items included questions designed to assess students' factual understanding of geometry concepts, their ability to apply their knowledge of geometry to problems from outside of books, and their ability to relate their understanding of geometry to real-world situations.

Table 1

Comparison of control and experimental groups before treatment on items related to the Concepts of Geometry

	Total Scores	Group	N	Mean	SD	*t*	df	*p*
Pretest: Sum of items related to the Concepts of Geometry	97	Control	35	.31	1.05	-.07	66	.88
		Experimental	33	.33	1.08			

Table 1 compares the mean scores of the experimental and the control group before treatment, on items related to the concepts of geometry. Since the result of Levene's Test for Equality of Variances was larger than.05 and had a significance value of.88, so equal variance was assumed. The p-value for both control and experimental group was .88 [N = 35, Mean = .31 and SD = 1.05 for control group and N = 33, Mean = .33, SD = 1.08 for experimental group. *t* value for both control and experimental groups was t (66) = -.07 at $p > .05$]. As *p* value was greater than .05 so there was statistically no significant difference between the groups on items involving the Concepts of Geometry before treatment.

Table 2

Comparison of control and experimental groups after the treatment on items related to the Concepts of Geometry

	Total Scores	Group	N	Mean	SD	*t*	df	*p*	*Eta* ^{2}
Posttest: Sum of items related to *the Concepts of Geometry*	97	Control	35	37.69	6.85	-45.61	34.40	.00	.96
		Experimental	33	90.73	.51				

Table 2 presents a comparison of the mean scores of experimental and control groups on Concepts of Geometry items after the intervention. Since Levene's Test for Equality of Variances yielded a value of significance equal to.00, which was less than.05, so equal variance was not assumed. The p-value for both control and experimental group was .00 [N

= 35, Mean = 37.69 and SD = 6.85 for control group and N = 33, Mean = 90.73, SD = .51 for experimental group. *t* value for both control and experimental groups was *t* (34.40) = - 45.61 at $p < .05$]. As *p* value was less than .05 so there was statistically significant difference between the groups after treatment in items related to the Concepts of Geometry, with $Eta^2 = .96$. The experimental group performed better than the control group on items related to the Concepts of Geometry.

Conclusion and Discussion

The study's findings indicated that, on items pertaining to Concepts of Geometry, students of equal ability in the experimental group fared better than those in the control group, with a greater effect size. Since the design and other arrangements addressed all potential risks to internal and external validity, it is possible that the experimental group's improved performance was a result of the teaching strategy that used analogies.

References

1. Benkoski, K. A. H., and Greenwood, S. C. (1995). The Use of Word Analogy Instructions with Developing Readers. *The Reading Teacher, 48 (5), 446-447.* http://doi.org/10.1111/j.1467-9604.tb00151.x
2. BM de Almeida, M. J., Salvador, A., & R. R Costa, M. M. (2014). Analogy for Drude's free electron model to promote students' understanding of electric circuits in lower secondary school. *Physics Education Research, 10, 1-12,* http://doi.org/10.1103/PhysRevSTPER.10.020118
3. Braasch, J. L., & Goldman, S. R. (2010). The role of prior knowledge in learning from analogies in science texts. *Discourse Processes*, *47*(6), 447-479. http://doi.org/10.1080/01638530903420960
4. Calik, M., Okur, M. & Taylor, N. (2011). A Comparison of Different Conceptual Change Pedagogies Employed within the Topic of "Sound Propagation". *Journal of Science Education and Technology, 20 (6), 729-742.* https://doi.org/10.1007/s10956-010-9266-z
5. Coley, J. D., & Tanner, K. D. (2012). Common origins of diverse misconceptions: Cognitive principles and the development of biology thinking. *CBE—Life Sciences Education*, *11*(3), 209-215, http://doi.org/10.1187/cbe.12-06-0074
6. Dahl, D. W., & Moreau, P. (2002). The Influence and Value of Analogical Thinking during New Product Ideation. *Journal of Marketing Research, 39 (1), 47-60.* http://doi.org/10.1509/jmkr.39.1.47.18930
7. Didiş, N. (2015). The analysis of analogy use in the teaching of introductory quantum theory. Chemistry Education: Research and Practice, Vol. 16, pp. 355 - 376. http://doi.org/10.1039/C5Rp00011D
8. DİDİŞ K, N. and Hıdır, M. (2019). How should textbook analogies be used in teaching physics? Physical Review Physics Education Research Vol. 15, http://doi.org/10.1103/PhysRevPhysEducRes.15.010109
9. Dilber. R., & Duzgun, B. (2008). Effectiveness of Analogy on Students' Success and Elimination of Misconceptions. *Latin American Journal of Physics Education, 2 (3), 174-183.* Retrieved from http://www.journal.lapen.org.mx
10. Duit, R. (1991). On the role of Analogies and Metaphors in Learning Science. *Science Education, 75 (6), 649-672.* http://doi.org/10.1002/sce.3730750606
11. Duit, R., Roth, W. M., Komorek, M., & Wilbers, J. (2001). Fostering conceptual change by analogies—between Scylla and Charybdis. *Learning and Instruction, 11(4), 283–303.* http://dx.doi.org/10.1016/S0959-4752(00)00034-7
12. Fotou, N., & Abrahams, I. (2020). Extending the role of analogies in the teaching of physics. *The*

Physics Teacher, *58*(1), 32-34. http://doi.org/10.1119/1.5141968
13. Gabel, D. (2003). Enhancing the Conceptual understanding of Science. *Educational Horizon, 81 (2), 70-76.* Retrieved from http://www.jstor.org/stable/42925990
14. Gay, A. S. (2008). Helping Teachers Connect Vocabulary and Conceptual Understanding. *The Mathematics Teacher, 102 (3) 218-223.* Retrieved from: http://www.jstor.org/stable/20876326
15. Gentner, D. (1983). Structure-Mapping: A Theoretical Framework for Analogy. *Cognitive Science, 7(2), 155-170.* https://doi.org/10.1016/S0364-0213(83)80009-3
16. Gentner, D., & Gentner. R. (1983). Flowing water or teeming crowds: Mental Models of Electricity. In D. Gentner & A. L. Stevens (Eds.) *Mental Models* (pp. 99-129). Hillsdale, NJ: Lawrence Erlbaum Associates.
17. Genter, D. (1998). Analogy. In w. Bechtel & G Graham (Eds.). *A Companion to Cognitive Science (pp. 107-113).* Oxford: Blackwell.
18. Gentner, D. & Smith, L. (2012). Analogical Reasoning. In V. S. Ramachandran, (Ed). *Encyclopedia of Human Behavior* (2nd Ed.), 130-136. Oxford, UK: Elsevier
19. Glynn, S. M., Yeany, R. H., & Briton, B. K. (1991). A Constructive view of learning Science. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The Psychology of Learning Science* (pp. 3-19). Hillsdale, NJ, US: Lawrence Erlbaum Associates, Inc.
20. Glynn, S. M. (1994). Teaching Science with Analogy: A Strategy for Teachers and Textbook Authors. National Research Reading Center, University of Georgia and Maryland, Reading Research Report No. 15. Retrieved from: http://files.eric.ed.gov/fulltext/ED373306.pdf
21. Glynn. S. M., & Takahashi, T. (1998). Learning from Analogy-Enhanced Science Text. *Journal of Research in Science Teaching, 35 (10), 1129-1149.* Retrieved from: https://doi.org/10.1002/(SICI)1098-2736(199812)35:10<1129::AID-TEA5>3.0.CO;2-2
22. Gokhan, U. G. U. R., Dilber, R., Senpolat, Y., & Duzgun, B. (2012). The effects of analogy on students' understanding of direct current circuits and attitudes towards physics lessons. *European journal of educational research*, *1*(3), 211-223. http://doi.org/10.12973/eu-jer.1.3.211
23. Gray, M. E., & Holyoak, K. J. (2021). Teaching by analogy: From theory to practice. *Mind, Brain, and Education*, *15*(3), 250-263. http://doi.org/10.1111/meb.12288
24. Haglund, J. (2013). Collaborative and self-generated analogies in science education. *Studies in science Education*, *49*(1), 35-68. https://doi.org/10.1080/03057267.2013.801119
25. Halpern, D. F., Hansen, C., & Riefer, D. (1990). Analogy as an Aid to Understanding and Memory. *Journal of Educational Psychology, 82 (2), 298-305.* http://dx.doi.org/10.1037/0022-0663.82.2.298
26. Harrison A.G., & Treagust, D.F. (1993). Teaching with analogies: A case study in grade 10 optics. *Journal of Research in Science Teaching*, 30, 1291-1307. http://doi.org/10.1002/tea.3660301010
27. Harrison, A.G., & Treagust, D.F. (2000). Learning about atoms, molecules and chemical bonds: a case-study of multiple model use in grade-11 chemistry. Science Education, 84(3), 352-381. http://doi.org/10.1002(SICI)1098-237X(200005)84:3<352::AID-SCE3>3.0.CO:2-J
28. Harrison, A. G., & Treagust, D. F. (2006). Teaching and learning with analogies, in Aubusson P. J., Harrison A. G. and Ritchie S. M. (ed.), Metaphor and Analogy in Science Education, Netherlands: Springer, pp 11–24.
29. Hıdır, M., & Didiş-Körhasan, N. (2018). Examination of the Analogies in Science Textbooks and Opinions of Science Educators about the Effective Use of Analogies. Necatibey Faculty of Education Electronic Journal of Science and Mathematics Education, 12 (2). http://doi.org/10.17522/balikesirnef.506455
30. Iding, M. K. (1997). How analogies foster learning from science text. *Instructional Science, 25 (4), 233-253.* https://doi.org/10.1023/A:1002987126719
31. Khan, A. A., & Mahmood, N. (2017). The Role of the Synectics Model in Enhancing Students' Understanding of Geometrical Concepts. *Journal of Research & Reflections in Education*

(JRRE), *11*(2). *pp. 253-264.*

32. Khan, A. A., & Mahmood, N. (2018). Effect of Synectics Model of Teaching in Enhancing Students' Understanding of Abstract Concepts of Mathematics. *PJDOL*, *4*(1), pp.185-198
33. Lee, K. H., & Sriraman, B. (2011). Conjecturing via Reconceived Classical Analogy. *Educational Studies in Mathematics, 76 (2), 123-140.* https://doi.org/10.1007/s10649-010-9274-1
34. Loc, N. P. (2015). A Study of Mathematics Education Students' Difficulties in Applying to Teaching Mathematics: A Case of the "TWA" Model. *American International Journal of Research in Humanities, Arts and Social Sciences, 9 (3), 276-280.* Retrieved from: http://www.iasir.net
35. Mason, L. (1994). Cognitive and Metacognitive Aspects in Conceptual Change by Analogy. *Instructional Science, 22* (3), 157-187. http://doi.org/10.1007/BF00892241
36. Mason, L., Sorzio, P. (1996). Analogical reasoning in restructuring scientific knowledge. *European Journal of Psychology of Education, 11 (1), 3-23.* http://doi.org/10.1007/BF03172933
37. Michael A. Martin (2003) "It's Like… You Know": The Use of Analogies and Heuristics in Teaching Introductory Statistical Methods, *Journal of Statistics Education, 11:2.* http://doi.org/10.1080/10691898.2003.11910705
38. Middleton, J. L. (1991). Student-Generated analogies in Biology. *The American Biology Teacher, 53 (1), 42-46,* https://doi.org/10.2307/4449212
39. Nersessian, N. J. (1988). Reasoning from Imagery and Analogy in Scientific Concept Formation. *Proceedings of the Biennial Meeting of the Philosophy of Science Association, 41-47.* Retrieved from: https://doi.org/10.1086/psaprocbienmeetp.1.19297
40. Newby, T. J., Ertmer, P. A., and Stepich, D. A. (1995). Instructional Analogies and the Learning of Concepts. *Educational Technology Research and Development, 43 (1), 5-18.* https://doi.org/10.1007/BF02300478
41. Pitterson, N., Perova-Mello, N., & Streveler, R. (2018). Engineering students' use of analogies and metaphors: Implications for educators. *International Journal of Engineering Education*, *35*, 2-14.
42. Ramos, M. T. G. (2011). Analogies as Tool for Meaning Making in Elementary Science Education: How Do They Work in Classroom Setting? *Eurasia Journal of Mathematics, Science and Technology Education. 7 (1), 29-39.* https://doi.org/10.12973/ejmste/75175
43. Ryan, C. E. (2006). Analogies are like Bowling Balls, or Why Analogies to English need some explanation to help students learn scheme. M. Sc. (CS) Thesis, Berkeley University of California. Retrieved from http://www2.eecs.berkeley.edu/Pubs/TechRpts/2006/EECS-2006-75.pdf
44. Silkebakken, G. P., & Camp, D. J. (1993). A five-step strategy for teaching analogous reasoning to middle school students. *Middle School Journal, 24 (4), 47-50.* Retrieved from: https://www.jstor.org/stable/23023141
45. Shana, Z. A., & El Shareef, M. A. (2022). Science Teachers' Use of Analogies: Findings from Classroom Practices. *European Journal of Educational Research, 11 (2), pp. 1023-1036.* http://doi.org/10.12973/eu-jer.11.2.1023
46. Staple, D. A., & Spears, R. (1996). Guilty by Disassociation (And Innocent by Association): The Impact of Relevant and Irrelevant Analogies on Political Judgement. Political Behavior, *18 (3), 289-309*. https://doi.org/10.1007/BF01498603
47. Stepich, D. A., & Newby, T. J. (1988). Analogical instruction within the information processing paradigm: Effective means to facilitate learning. *Instructional Science*, *17(2), 129-144.* https://doi.org/10.10007/BF00052699
48. Szetela, W. (1980). Analogy and Problem Solving: A Tool for Helping Children to develop a Better Concept of Capacity. *Journal of Educational Psychology, 82, 298-305.* https://doi.org/10.2307/41189598
49. Taber, K. S. (2001). When the analogy breaks down: modelling the atom on the solar system, *Physics Education*, 36(3), 222–226. https://doi.org/10.1088/0031-9120/36/3/308
50. Thiele, R. B., & Treagust, D. F. (1992). Analogies in senior High School Chemistry Textbooks.

Proceedings of ICASE Research Conference in Chemistry and Physics Education. Dortmund, Germany, June 10-12, 1992. Retrieved from: https://files.eric.ed.gov/fulltext/ED357966.pdf

51. Thiele, R. B., & Treagust, D. F. (1994). The nature and extent of analogies in Secondary textbook. *Instructional Science, 22 (1), 61-74.* https://doi.org/10.1007/BF00889523
52. Thiele, R. B., & Treagust, D. F. (1994). An interpretive examination of high school chemistry teachers' analogical explanations. *Journal of Research in Science Teaching*, *31(3), 227-242.* http://doi.org/10.1002/3660310304
53. Thiele, R. B., & Treagust, D. F. (1994). The nature and extent of analogies in Secondary textbook. *Instructional Science, 22 (1), 61-74.* https://doi.org/10.1007/BF00889523
54. Thiele, R. B., & Treagust, D. F. (1992). Analogies in senior High School Chemistry Textbooks. Proceedings of ICASE Research Conference in Chemistry and Physics Education. Dortmund, Germany, June 10-12, 1992. Retrieved from: https://files.eric.ed.gov/fulltext/ED357966.pdf
55. Treagust, D. F., Harrison, A. G., & Venville, G. J. (1998). Teaching Science Effectively with Analogies: An Approach for Preservice and In-service Teacher Education. *Journal of Science Teacher Education*, *9(2), 85–101*. https://doi.org/10.1023/A:1009423030880
56. Treagust, D. F., Stocklmayer, S. M., Harrison, A., Venville, G., & Thiele, R. (1994). Observations from the Classroom: When analogies go wrong! *Research in Science Education*, *24, 380-381*. https://doi.org/10.1007/BF02356372
57. Venville, G. J., Treagust, D. F. (1996). The role of analogies in promoting conceptual change in biology. *Instructional Science, 24 (4), 295-320.* https://doi.org/10.1007/BF00118053
58. Venille, G. J., and Treagust, D. F. (1997). Analogies in Biology Education: A Contentious Issue. *The American Biology Teacher, 59 (5), 282-287.* https://doi.org/10.2307/4450309
59. Zook, K. B. (1991). Effect of analogical processes to on learning and misrepresentation. *Educational Psychology Review, 3 (1, 41-72).* http://doi.org.10.1007/BF01323662