The Use of Analogies in Biology and Chemistry at Secondary School Level

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Abstract

Teachers' perceptions of analogy use in biology and chemistry teaching were investigated. The three research questions were: What do biology and chemistry teachers think about the use, benefits and limitations of analogies? What are teachers' perspectives on using analogies? What are teachers' perspectives on students' analogy construction?

Biology and chemistry teachers answered a questionnaire. The first section yielded descriptive statistics about: the advantages/disadvantages of the use of analogies; different analogies cited by teachers; and the topics where analogies are mostly used. The second section contained Likert scale items that generated inferences about the teacher population and comparisons between biology, chemistry and teachers of both subjects. Ten teacher interviews – five per subject – allowed for deeper insights on the last two research questions, where a student worksheet (having two sections: an analogy and students constructing an analogy) was discussed.

Most teachers agreed that advantages of analogies outweigh disadvantages. They expressed the need for further training on the effective use of analogies and the mitigation of disadvantages. Student analogy construction raised diverging reactions, with teachers suggesting possible advantages to analogy interpretation alongside further challenges.

Keywords: analogies, biology, chemistry, secondary school

1. Introduction

Science teachers always try to find ways of rendering lessons interesting and scientific concepts more accessible. Different models are used in teaching, including: two- and three-dimensional models, visual or verbal metaphors and analogies [4]. Analogies differ from other models since they are not an exact replica of the target. They are comparisons between the analogue (something which is familiar) and the target (which is not familiar). The use of analogies is a natural way of how people learn and try to make sense out of new information. This study investigates whether science teachers are making good use of analogies and considerations that they should be aware of when using analogies, such as advantages, disadvantages and limitations.

2. Theoretical background on analogies

Analogies are a type of model that can help students' understanding of a particular phenomenon or concept. They can provide a concrete reference for making sense of new and abstract concepts [11]. Science education can be considered as the understanding of the models and analogies used by scientists. This justifies the use of models in the teaching of science [6]. Analogy use can facilitate the construction of knowledge and should be considered as a fundamental tool in the teaching and learning of science. Analogical reasoning is widely used between experts and Nobel prize winners when trying to make sense of new concepts or communicating science [12].

'The structure mapping theory' defines an analogy as the process whereby unfamiliar knowledge is 'mapped' onto another better-known concept, classifies different types of comparisons, and provides a framework through which an analogy can be interpreted and scrutinised [6]. Structure mapping between the source and the target domains leads to the formation of schemas and the development of a relational system. The latter purports higher order thinking and mastery of the concept. This is of particular importance in science education as it drives conceptual change [12].

Analogies are successful tools if teachers and students are aware of their limitations and where the analogy breaks down [3] [6] [7]. Analogies can lead to misconceptions [3] if students inappropriately map the analogue and the target [9]. The effectiveness of an analogy depends on various factors, as the concept in question, the students' previous knowledge, the presentation mode and the level of student involvement during the target-source mapping process [9]. Misconceptions can be eliminated by: teachers pointing out similarities between analogy and target [2] [10]; using multiple analogies for the same concept [8]; using familiar analogue concepts that are relevant [8]; and asking students to generate their own analogies and discuss where their analogy breaks down [8]. The limited working memory of some students (which is age dependant) can be an issue [12].

Various models have been proposed for the effective use of analogies to reduce the potential limitations described above. These are: the General Model of Analogy Teaching (GMAT) [14]; Teaching with Analogies (TWA) [8]; Bridging Analogies [4]; the Focus, Action, Reflection (FAR) guide [13]; the Chemical Observation, Representation, Experimentation (CORE) cycle [1].

3. Methodology

The research tools were questionnaires and interviews. A mixture of descriptive and inferential statistics was used to analyse the two sections of the questionnaire: (i) Section 1, with five questions about advantages/disadvantages and examples of analogies, was analyzed using descriptive statistics; and (ii) Section 2, having 15 Likert Scale items regarding the usefulness of analogies, with space for further comments for seven of them, was analyzed using the Friedman test to compare means scores and the Kruskal-Wallis test to compare the statements for the three groups of (biology, chemistry, biology-chemistry) teachers. All biology and chemistry teachers in state and church schools in Malta were invited to answer the questionnaire. The 73 responses accounted for a margin of error of 7% with a 95% confidence level.

Convenience sampling was used to invite teachers for the online interviews. A total of ten interviews – five each with biology and chemistry teachers – were carried out. They were based on a set of structured questions regarding a student worksheet and its corresponding marking sheet. The biology worksheet had Task A about interpreting DNA analogies and Task B was constructing an analogy for viral replication. The chemistry worksheet had Task A about interpreting an analogy for polymers and Task B about the construction of an analogy for ionic bonding.

4. Results and Discussion

4.1 Questionnaire results – Descriptive statistics

Most teachers (83.6%) correctly defined analogies as 'comparisons used for understanding'. The emphasis on 'understanding' indicated that other uses of analogies, as higher order thinking skills, are not as familiar. 12.3% of the sample confused 'analogy' with the use of examples to explain concepts (also found in [10]). There were other erroneous definitions as: the breakdown of lengthy terminology (e.g., photosynthesis) into its components. Teachers reported more advantages (106) than disadvantages (77) for analogies, as shown in Figure 1. One notes that promoting meaningful learning [10] did not feature while higher order thinking activities [11] did not register a high frequency (only at 3.8%) and was only cited by four teachers (5.5%). Thus, teachers are not so aware of the full potential that analogies can confer.

The results in Figure 2 indicate two main concerns: a staggering 68.9% of the total disadvantages mentioned by teachers are the generation of misconceptions and misunderstandings that may arise if students do not understand the analogy well. Concerns related to the generation of misconceptions are pointed out by various literature sources [3] [8] [11]. The apprehension associated with confusion if students do not understand the similarity between the analogue and the target, is also pointed out by Bellocchi & Ritchie [2] and Haglund [10].

When teachers were asked to give examples of analogies, the chemistry analogies were more complex than the biology ones since the similarities between the source and target domains were functional rather than structural. Out of the 14 biology topics for analogies mentioned, the most popular (45.5%) analogies were from ‘human body systems’, followed by transport across membranes (15.2%) and cytology (12.1%). The chemistry teachers were less ‘ordered’, both in terms of the number of topics mentioned, and the frequencies within each of these 18 topics. The top three choices for chemistry topics were bonding (22.4%), kinetic theory of matter (13.8%) and equilibria (12.1%). Bonding is a ubiquitous top choice for the use of analogies. This is not surprising since it is both challenging to comprehend for students and a field of study where chemists themselves utilise analogies to elucidate associated concepts [5].

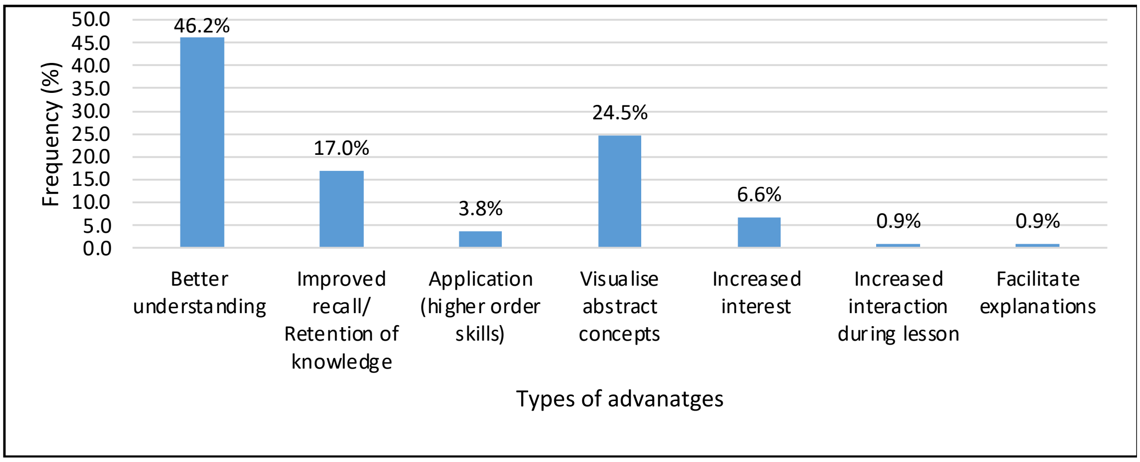


Figure 1: The frequency (%) of the types of advantages related to the use of analogies

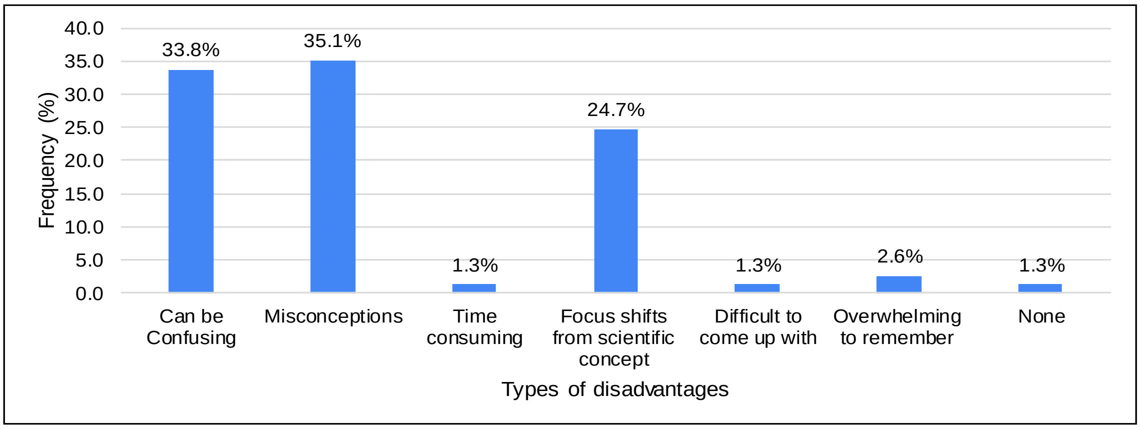
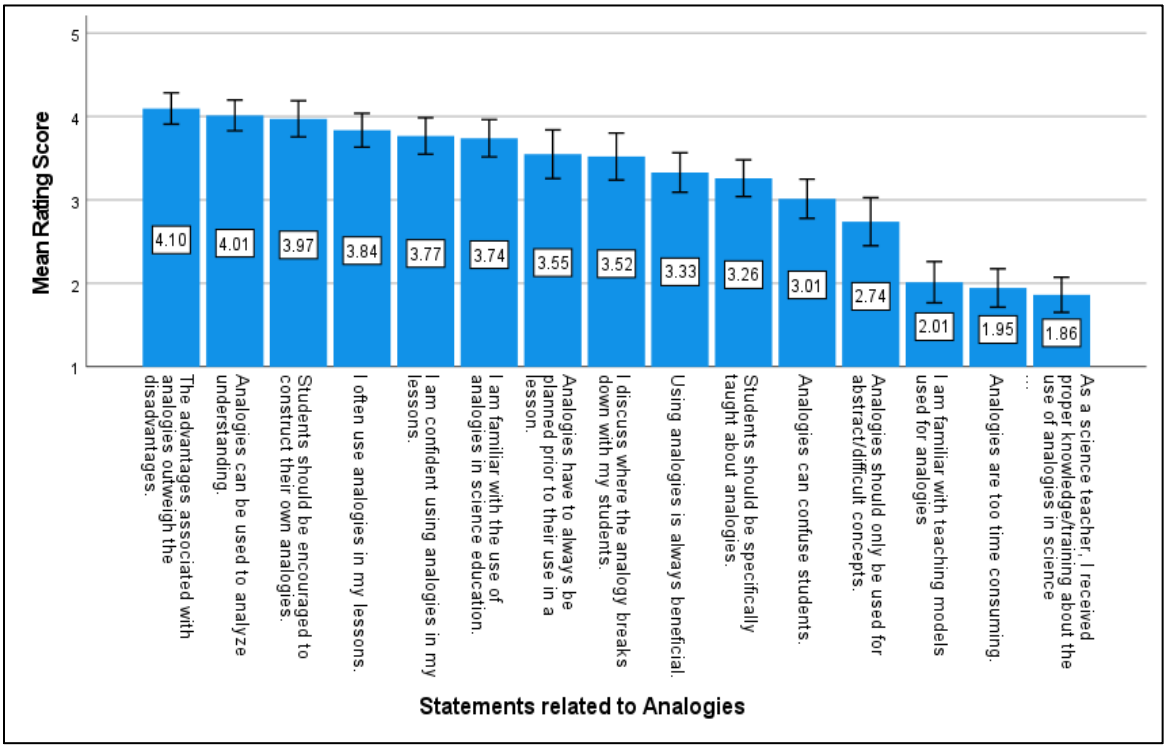


Figure 2: The frequency (%) of the types of disadvantages related to the use of analogies

4.2 Questionnaire results – the Friedman and Kruskal-Wallis test

The mean rating scores for the Likert scale items ranged from 1 (strongly disagree) to 5 (strongly agree). Thus, the larger the mean rating score, the higher the agreement. The mean rating scores are considered to vary significantly if the p-value is less than 0.05. The results and the test statistics for the Friedman test are shown in Figure 3. The error bars display the 95% confidence intervals of the actual mean rating scores for each statement if the whole population of Maltese biology and chemistry teachers were to be considered. It can be inferred that if the questionnaire were answered by the whole population of teachers, the last three statements in Figure 3 would rank last (but not necessarily in the same order) because their error bars are disjointed from the other 12 statements. This suggests that teachers are not conversant with literature and do not feel properly trained in using analogies. 47.9% of respondents provided further comments, with a number of ‘complaints’ about lack of training in such fields.

The Kruskal-Wallis test was used to compare the mean rating scores per statement between the three groups of teachers. Statistical significance is reached if the p-value is less than 0.05. The only statement where biology teachers had a significantly ($p = 0.045$) higher mean (4.32) than chemistry teachers (3.9) and teachers teaching both subjects (3.7) was the statement asserting that the



advantages associated with analogies outweigh the disadvantages. Since chemistry topics tend to be more abstract and complex the associated analogies tend to be more complex. This explains why chemistry teachers disagree more significantly compared to biology teachers.

Figure 3: The mean rating scores and error bars for the 15 statements. $\chi^2(14) = 389.295$, $p < 0.001$

4.3 Interview results

All biology and chemistry teachers commented that interpreting a given analogy is an ‘easier’ task compared to asking students to construct one. All biology teachers liked the ‘given’ ladder analogy for the structure of DNA, but the feeling was not mutual for the ‘computer-code’ analogy. The latter is more complex, and teachers felt it was too cumbersome for some students to understand. Some teachers also commented that even they struggled to answer the worksheet questions prior to seeing the marking scheme.

Chemistry teachers were unanimous in considering the ‘train analogy’ to explain addition polymerization as appropriate. Teachers presented contrasting arguments on whether the polymer analogy should be discussed in depth, as the questions in the worksheet aimed to. Similarly, some chemistry teachers asserted that certain worksheet questions asking for an in-depth critique of the analogy was too much for students since they found them challenging themselves. Other chemistry teachers commented that this can provide a deeper level of understanding and aid students in critical thinking skills. This led to contrasting arguments on whether analogies should be used with higher ability students or only as a ‘last resort’ with lower ability students. This dilemma also emerged when discussing students’ ability to construct analogies. Some teachers affirmed that students who struggle to understand a concept can be more creative and come up with analogies to assist their understanding. Others commented that this requires higher-order thinking skills, and thus should be appropriately used with higher-ability students.

Chemistry teachers showed higher concern about the topic chosen in the worksheet – ionic bonding – than biology teachers did for viral replication. Most chemistry teachers asserted that bonding is too complex, and that they try to avoid misconceptions by limiting the use of analogies, out of ‘fear’ of compromising the scientific concept. Biology teachers were mostly concerned with time-constraints imposed by the lengthy syllabus. Teachers agreed that the use of student generated analogies as assessment tools can be challenging due to subjectivity. Most teachers stated that they would assess students' analogies through qualitative methods (students explaining their reasoning behind their analogy) rather than quantitative ones (using marks).

5. Conclusion

If higher order thinking is a component of the set of 21st century skills, why aren't we using simple tools as analogies to help in achieving these skills? Teachers fear analogy limitations and shy away from investing time and effort in utilizing them to achieve higher order thinking. The study indicates the need for better teacher training, to equip teachers with the skills needed to use analogies and to avoid related concerns. Most teachers were intrigued by and realised that there are several aspects they never thought of when planning and using analogies. For most teachers, asking students to construct analogies or discussing the limitations of an analogy were unfamiliar territories. Teachers also suggested that since using analogies requires critical thinking skills, they should be used throughout the curriculum and not just in science, thus facilitating their use as higher order thinking activities and eliminating the 'novelty' variable.

Further research could explore student generated analogies as a different mode of formative and summative assessment.

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